EN2042102 วงจรไฟฟ้าและอิเล็กทรอนิกส์

Circuits and Electronics

บทที่ 1 พื้นฐานทางไฟฟ้า

สาขาวิชาวิศวกรรมคอมพิวเตอร์
คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเทคโนโลยีราชมงคลพระนคร

วัตถุประสงค์ (OBJECTIVES)

- บอกวัดทางไฟฟ้า และหน่วยวัดทางปริมาณที่ใช้ในทางไฟฟ้า
- บอกหน่วยวัดระบบเอสไอ (SI system) ที่ใช้ในทางไฟฟ้าและอิเล็กทรอนิกส์
- แปลงหน่วยวัดทางปริมาณต่าง ๆ
- บอกโครงสร้างอะตอมของตัวนำ เช่น ทองแดง
- เข้าการทำการของแหล่งจ่ายไฟฟ้า เช่น แบตเตอรี่ และแหล่งจ่ายไฟฟ้ากระแสตรงชนิดต่าง ๆ
- เข้าใจหลักการทำงานของตัวต้านทานได้
- เข้าใจหลักการของเซมิคอนดักเตอร์
- บอกชนิดของอุปกรณ์อิเล็กทรอนิกส์ต่าง ๆ ที่ใช้หลักการของความต้านทาน

LOGO

พื้นฐานทางไฟฟ้า

POWERS OF TEN

- It should be apparent from the relative magnitude of the various units of measurement that very large and very small numbers are frequently encountered in the sciences.
- To ease the difficulty of mathematical operations with numbers of such varying size, *powers of ten* are usually employed.
- This notation takes full advantage of the mathematical properties of powers of ten.

LOGO

POWERS OF TEN

- The notation used to represent numbers that are integer powers of ten is as follows:

$$
\begin{aligned}
1 &= 10^0 & 1/10 &= 0.1 = 10^{-1} \\
10 &= 10^1 & 1/100 &= 0.01 = 10^{-2} \\
100 &= 10^2 & 1/1000 &= 0.001 = 10^{-3} \\
1000 &= 10^3 & 1/10{,}000 &= 0.0001 = 10^{-4}
\end{aligned}
$$

LOGO

FIXED-POINT, FLOATING-POINT, SCIENTIFIC, AND ENGINEERING NOTATION

- **Scientific (**also called *standard*) **notation** and **engineering notation** make use of powers of ten, with restrictions on the mantissa (multiplier) or scale factor (power of ten).
- **Engineering notation** specifies that *all powers of ten must be 0 or multiples of 3, and the mantissa must be greater than or equal to 1 but less than 1000.*

LOGO

FIXED-POINT, FLOATING-POINT, SCIENTIFIC, AND ENGINEERING NOTATION

Prefixes

Multiplication Factors	SI Prefix	SI Symbol
$1\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{18}$	exa	E
$1\ 000\ 000\ 000\ 000\ 000 = 10^{15}$	peta	P
$1\ 000\ 000\ 000\ 000 = 10^{12}$	tera	T
$1\ 000\ 000\ 000 = 10^{9}$	giga	G
$1\ 000\ 000 = 10^{6}$	mega	M
$1\ 000 = 10^{3}$	kilo	k
$0.001 = 10^{-3}$	milli	m
$0.000\ 001 = 10^{-6}$	micro	μ
$0.000\ 000\ 001 = 10^{-9}$	nano	n
$0.000\ 000\ 000\ 001 = 10^{-12}$	pico	p
$0.000\ 000\ 000\ 000\ 001 = 10^{-15}$	femto	f
$0.000\ 000\ 000\ 000\ 000\ 001 = 10^{-18}$	atto	a

TABLE 1.2

LOGO

แรงดันไฟฟ้า และกระแสไฟฟ้า

INTRODUCTION

- Now that the foundation for the study of electricity/electronics has been established, the concepts of voltage and current can be investigated.
  - The term **voltage** is encountered practically every day.
  - We are aware that most outlets in our homes are 220 volts.
- Although **current** may be a less familiar term, we know what happens when we place too many appliances on the same outlet—the circuit breaker opens due to the excessive current that results.

LOGO

ATOMS AND THEIR STRUCTURE

- A basic understanding of the fundamental concepts of current and voltage requires a degree of familiarity with the atom and its structure.
  - The simplest of all atoms is the hydrogen atom, made up of two basic particles, the **proton** and the **electron.**
  - The **nucleus** of the hydrogen atom is the proton, a positively charged particle.
    - *The orbiting electron carries a negative charge equal in magnitude to the positive charge of the proton.*

LOGO

ATOMS AND THEIR STRUCTURE

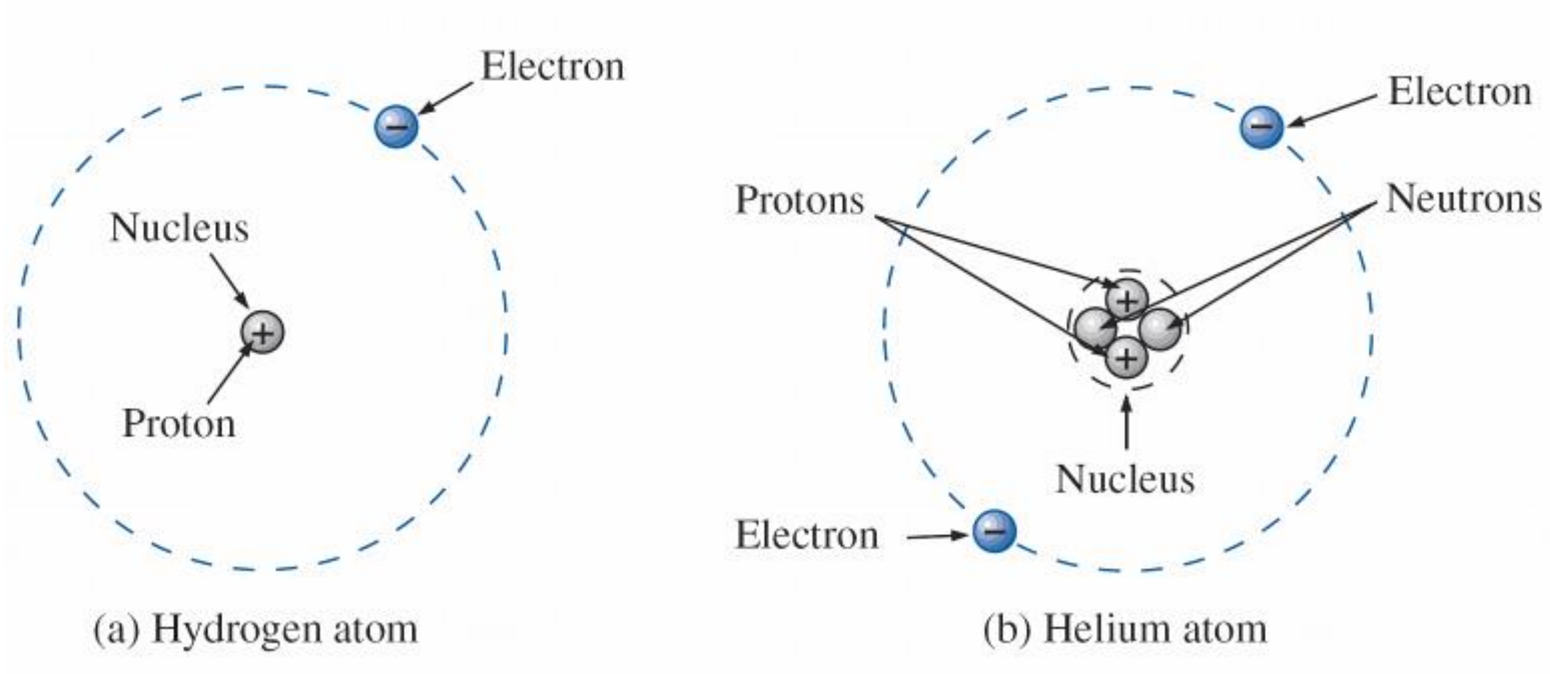


FIG. 2.1 *Hydrogen and helium atoms.*

LOGO

ATOMS AND THEIR STRUCTURE

- **Copper** is the most commonly used metal in the electrical/electronics industry.
- An examination of its atomic structure will reveal why it has such widespread application.
- It has 29 electrons in orbits around the nucleus, with the 29th electron appearing all by itself in the 4^{th} shell.

LOGO

ATOMS AND THEIR STRUCTURE

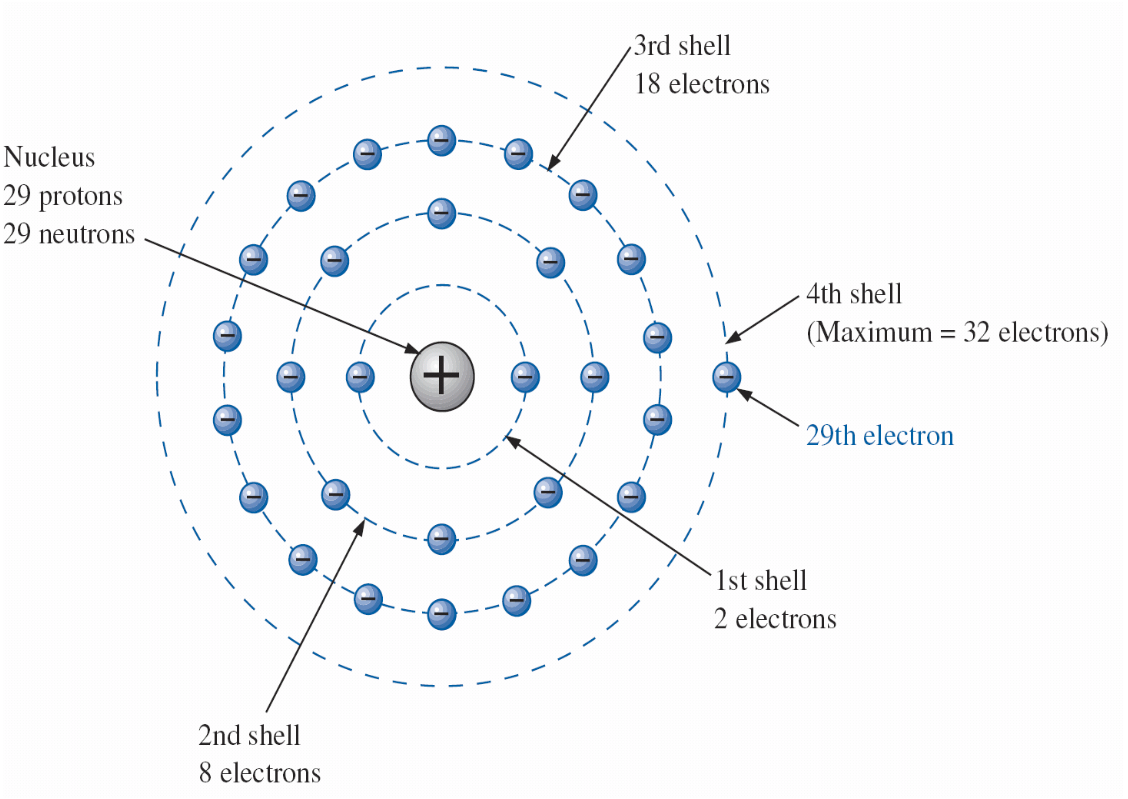


FIG. 2.2 *The atomic structure of copper.*

LOGO

VOLTAGE

- Since it would be inconsequential to talk about the voltage established by the separation of a single electron, a package of electrons called a **coulomb (C)** of charge was defined as follows:
  - *One coulomb of charge is the total charge associated with 6.242 x* 10^{18} *electrons.*
  - *If a total of 1 joule (J) of energy is used to move the negative charge of 1 coulomb (C), there is a difference of 1 volt (V) between the two points.*

LOGO

VOLTAGE

- Since the **potential energy** associated with a body is defined by its position, the term *potential* is often applied to define voltage levels.
  - For example, the difference in potential is 4 V between the two points, or the **potential difference** between a point and ground is 12 V, and so on.

LOGO

CURRENT

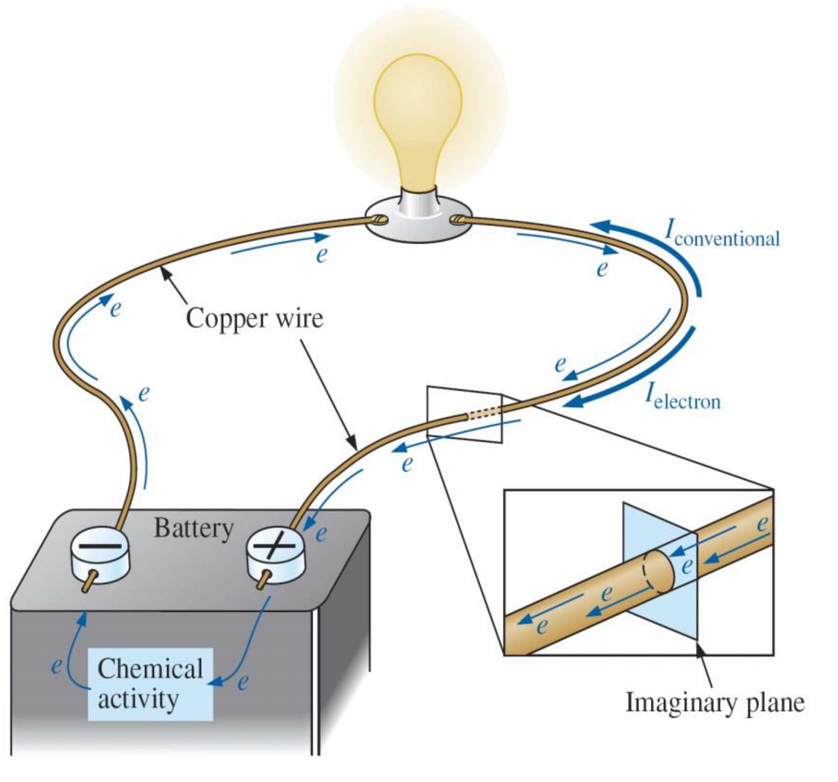


FIG. 2.9 *Basic electric circuit.*

CURRENT

- The unit of current measurement, **ampere**, was chosen to honor the efforts of André Ampère in the study of electricity in motion.
- In summary, therefore, *the applied voltage (or potential difference) in an electrical/electronics system is the "pressure" to set the system in motion, and the current is the reaction to that pressure.*

VOLTAGE SOURCES

- The term **dc,** used throughout this text, is an abbreviation for **direct current,** which encompasses all systems where there is a unidirectional (one direction) flow of charge.

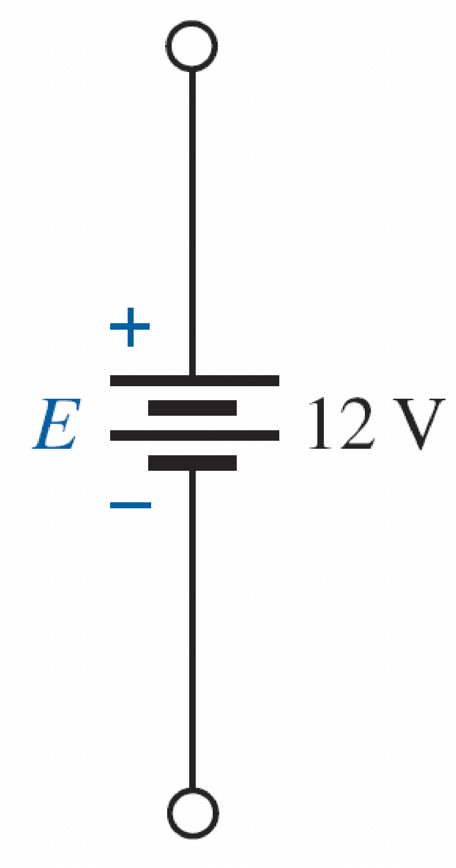


FIG. 2.11 *Standard symbol for a dc voltage source.*

LOGO

VOLTAGE SOURCES

- In general, dc voltage sources can be divided into three basic types:
  - Batteries (chemical action or solar energy)
  - Generators (electromechanical), and
  - Power supplies (rectification—a conversion process to be described in your electronics courses).

LOGO

VOLTAGE SOURCES

Batteries

- **General Information**
- **Primary Cells (Non-rechargeable)**
- **Secondary Cells (Rechargeable)**
  - *Lead-Acid*
  - *Nickel–Metal Hydride (NiMH)*
  - *Lithium-ion (Li-ion)*

VOLTAGE SOURCES

Batteries

FIG. 2.12 *Alkaline primary cell: (a) Cutaway of cylindrical Energizer® cell; (b) various types of Eveready Energizer® primary cells.*

LOGO

VOLTAGE SOURCES

Batteries

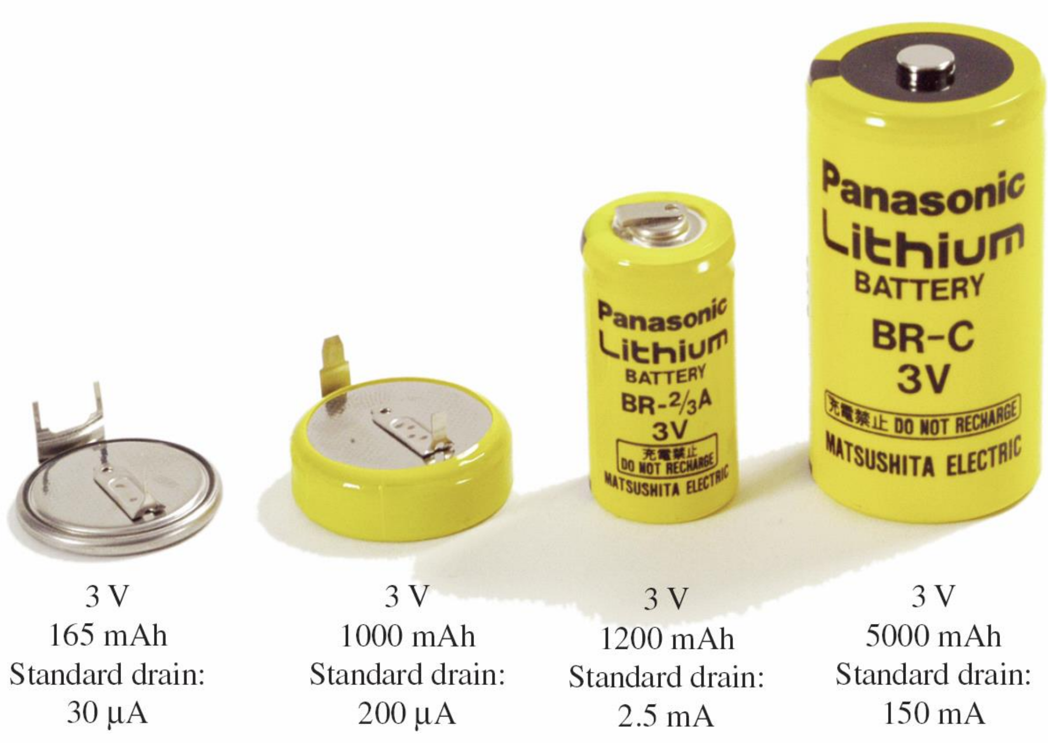


FIG. 2.13 *Lithium primary batteries.*

LOGO

VOLTAGE SOURCES

Batteries

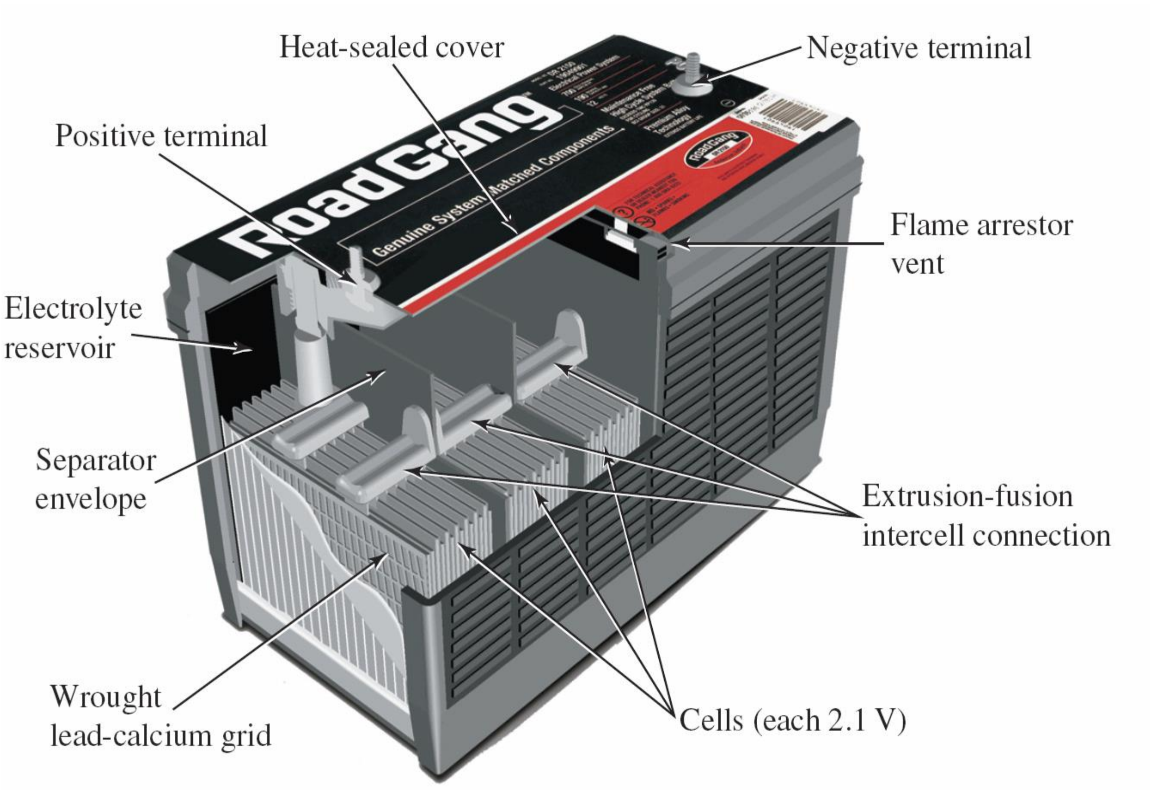


FIG. 2.14 *Maintenance-free 12 V (actually 12.6 V) lead-acid battery.*

LOGO

VOLTAGE SOURCES

Batteries

FIG. 2.15 *Nickel–metal hydride (NiMH) rechargeable batteries.*

LOGO

VOLTAGE SOURCES

Batteries

FIG. 2.16 *Dell laptop lithium-ion battery: 11.1 V, 4400 mAh.*

LOGO

VOLTAGE SOURCES

Solar Cell

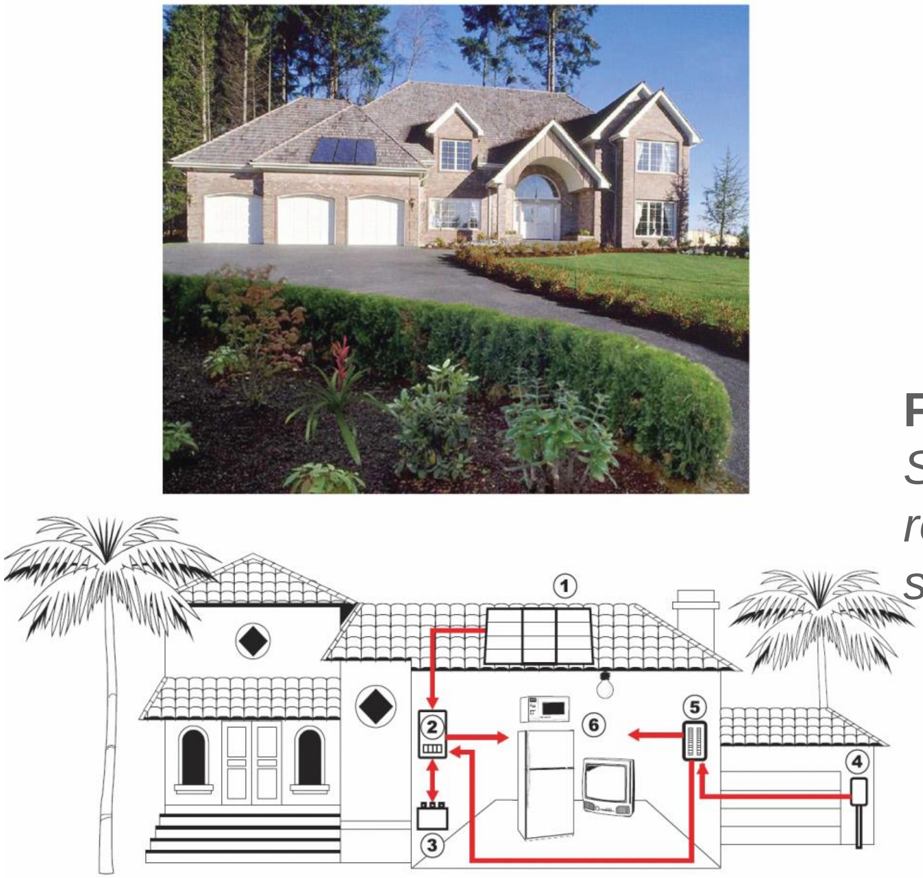


FIG. 2.17 *Solar System: (a) panels on roof of garage; (b) system operation.*

VOLTAGE SOURCES

Generators

- The **dc generator** is quite different from the battery, both in construction and in mode of operation.
- When the shaft of the generator is rotating at the nameplate speed due to the applied torque of some external source of mechanical power, a voltage of rated value appears across the external terminals.
- The terminal voltage and power-handling capabilities of the dc generator are typically higher than those of most batteries, and its lifetime is determined only by its construction.

LOGO

VOLTAGE SOURCES

Generators

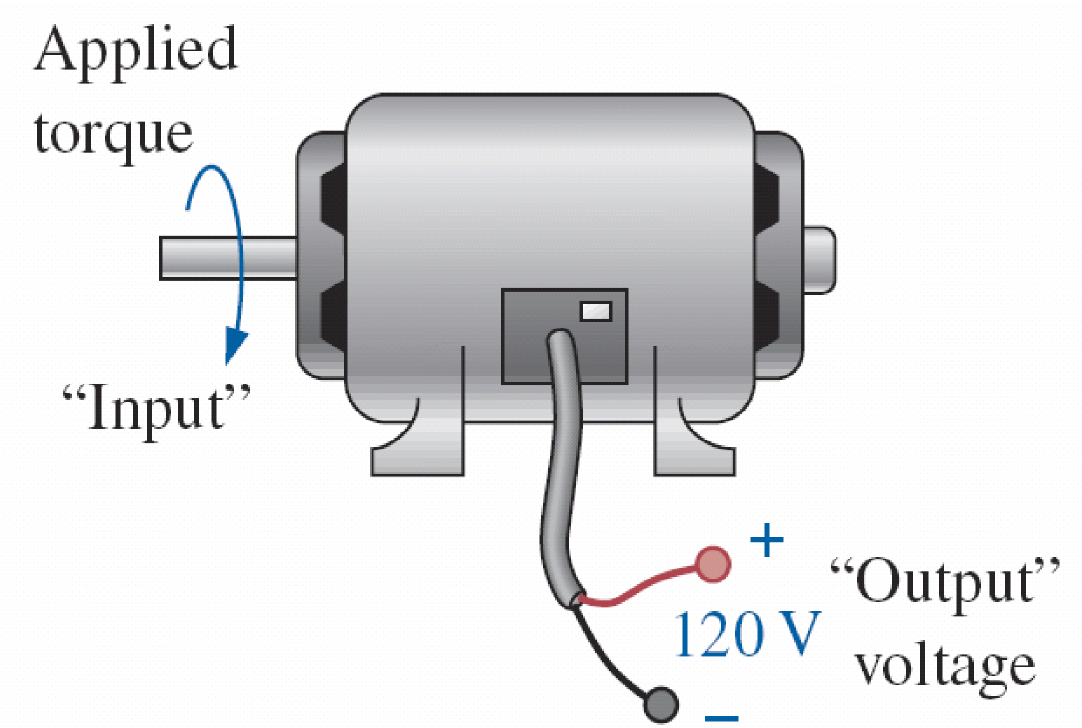


FIG. 2.18 *dc generator.*

LOGO

VOLTAGE SOURCES

Power Supplies

- The dc supply encountered most frequently in the laboratory uses the **rectification** and *filtering* processes as its means toward obtaining a steady dc voltage.

FIG. 2.19 *A 0 V to 60 V, 0 to 1.5 A digital display dc power supply*

LOGO

CONDUCTORS AND INSULATORS

- Different wires placed across the same two battery terminals allow different amounts of charge to flow between the terminals.
- Many factors, such as the density, mobility, and stability characteristics of a material, account for these variations in charge flow.
  - In general, however, ***conductors are those materials that permit a generous flow of electrons with very little external force (voltage) applied.***
  - In addition, ***good conductors typically have only one electron in the valence (most distant from the nucleus) ring.***

LOGO

CONDUCTORS AND INSULATORS

Metal	Relative Conductivity (%)
Silver	105
Copper	**100**
Gold	70.5
Aluminum	61
Tungsten	31.2
Nickel	22.1
Iron	14
Constantan	3.52
Nichrome	1.73
Calorite	1.44

TABLE 2.1 *Relative conductivity of various materials*

LOGO

CONDUCTORS AND INSULATORS

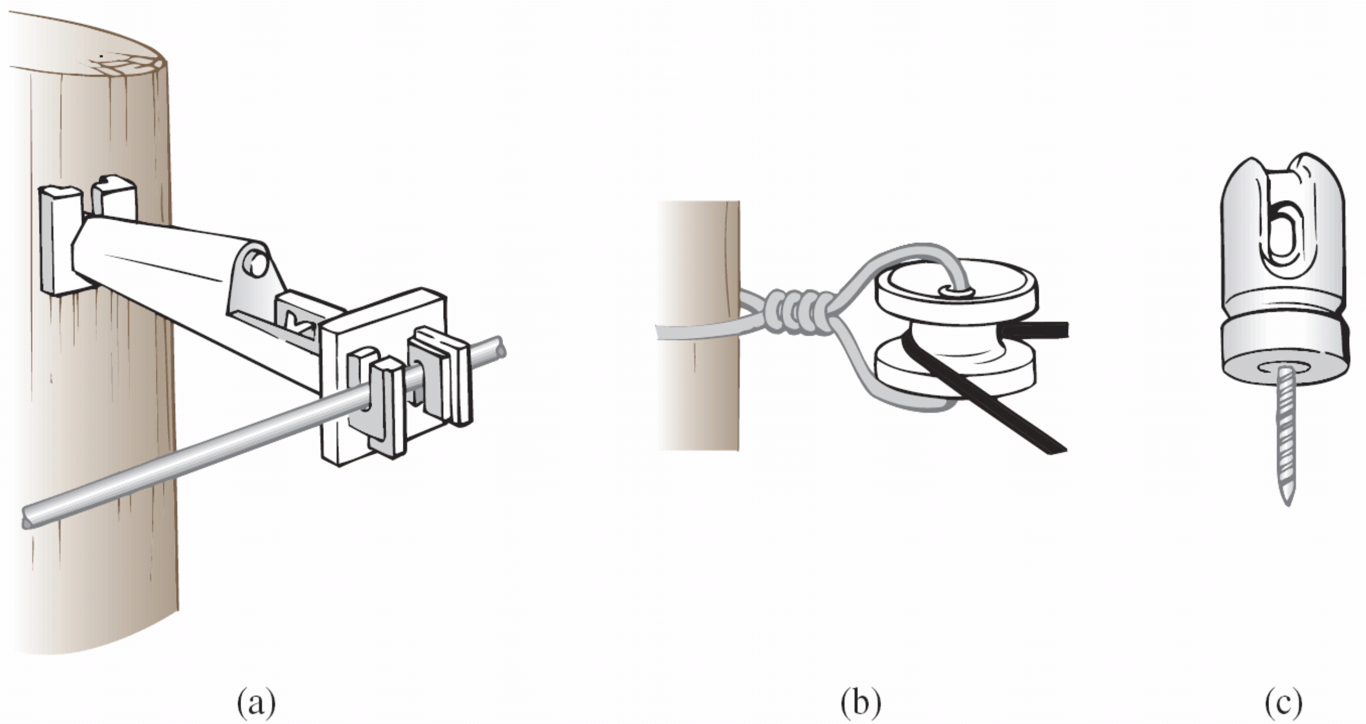


FIG. 2.26 *Various types of insulators and their applications. (a) Fi-Shock extender insulator; (b) Fi-Shock corner insulator; (c) Fi-Shock screw-in post insulator.*

LOGO

CONDUCTORS AND INSULATORS

Material	Average Breakdown Strength (kV/cm)
Air	30
Porcelain	70
Oils	140
Bakelite®	150
Rubber	270
Paper (paraffin-coated)	500
Teflon®	600
Glass	900
Mica	2000

TABLE 2.2 *Breakdown strength of some common insulators.*

LOGO

AMMETERS AND VOLTMETERS

- It is important to be able to measure the current and voltage levels of an operating electrical system to check its operation, isolate malfunctions, and investigate effects impossible to predict on paper.
- As the names imply, **ammeters** are used to measure current levels; **voltmeters,** the potential difference between two points.
- If the current levels are usually of the order of milliamperes, the instrument will typically be referred to as a *milliammeter,* and if the current levels are in the microampere range, as a *microammeter*.

LOGO

AMMETERS AND VOLTMETERS

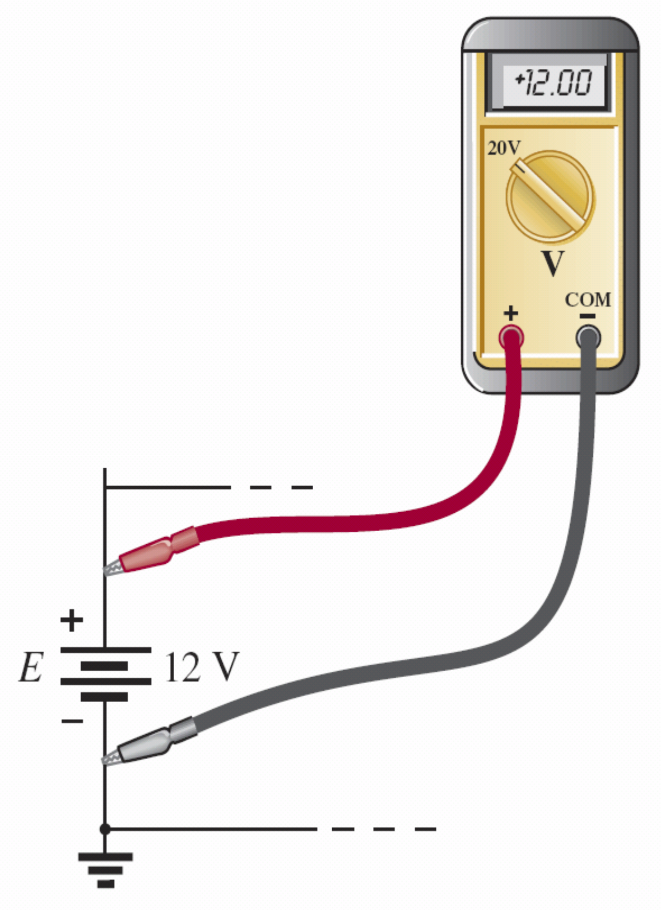


FIG. 2.27 *Voltmeter connection for an up-scale (+) reading.*

LOGO

AMMETERS AND VOLTMETERS

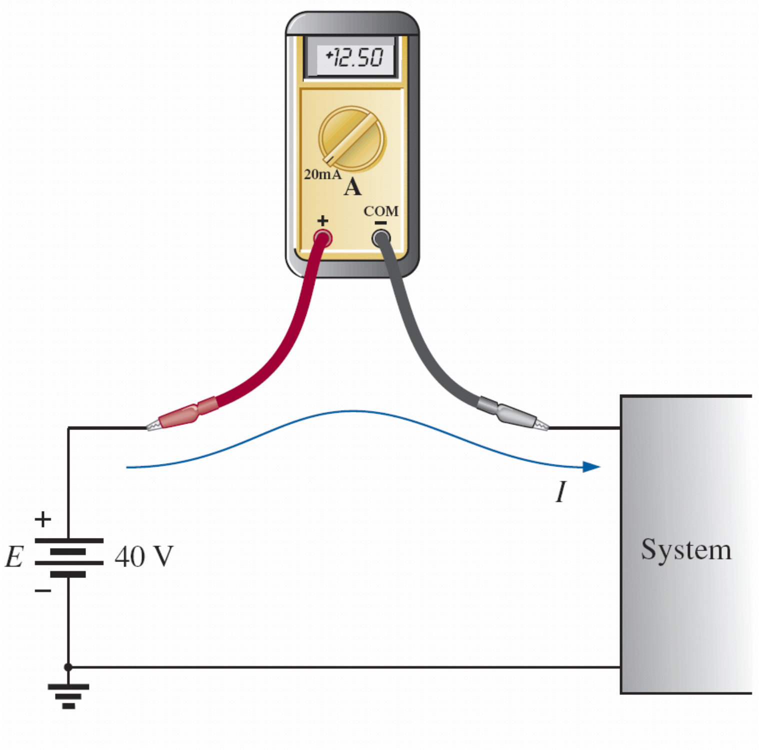


FIG. 2.28 *Ammeter connection for an up-scale (+) reading.*

AMMETERS AND VOLTMETERS

FIG. 2.29 *Volt-ohm-milliammeter (VOM) analog meter.*

LOGO

AMMETERS AND VOLTMETERS

FIG. 2.30 *Digital multimeter (DMM).*

LOGO

APPLICATIONS

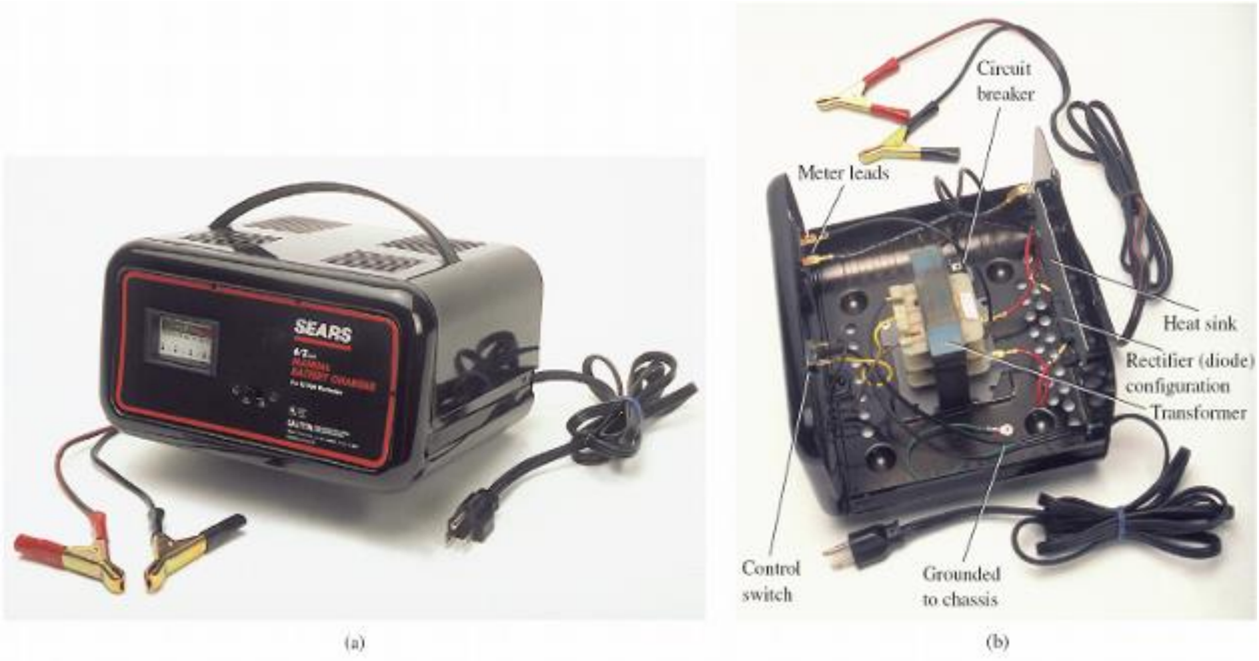


FIG. 2.32 *Battery charger: (a) external appearance; (b) internal construction.*

LOGO

APPLICATIONS

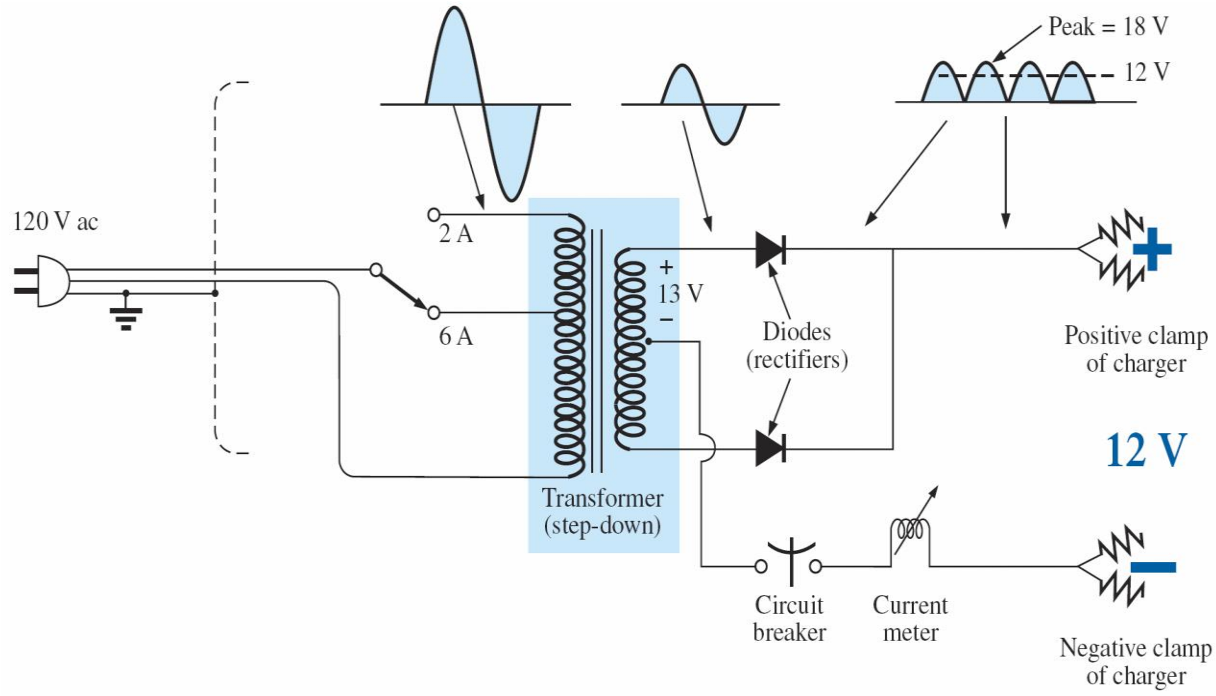


FIG. 2.33 *Electrical schematic for the battery charger of Fig. 2.32.*

LOGO

APPLICATIONS

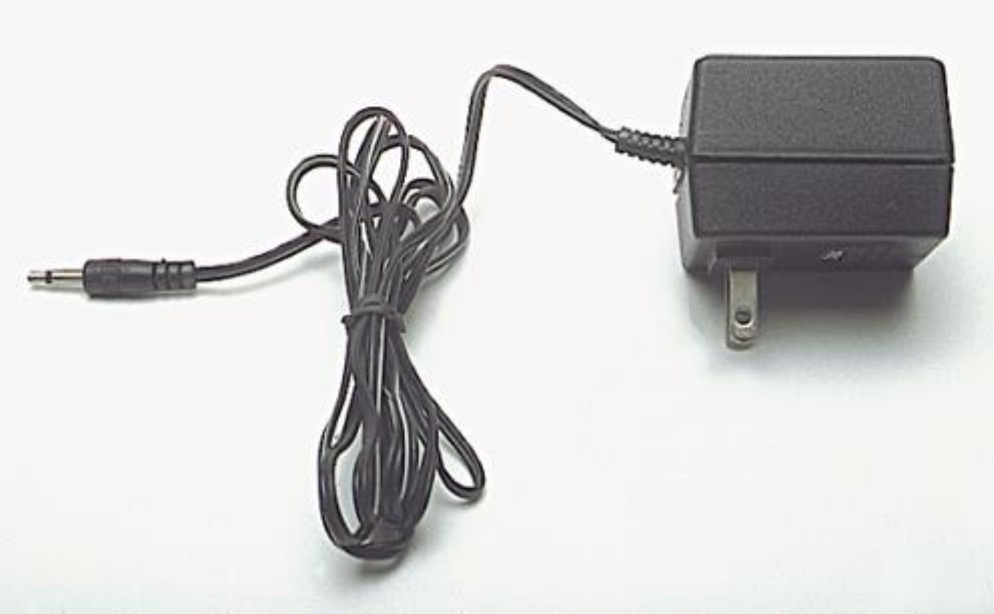


FIG. 2.34 *Answering machine/phone 9 V dc supply.*

LOGO

APPLICATIONS

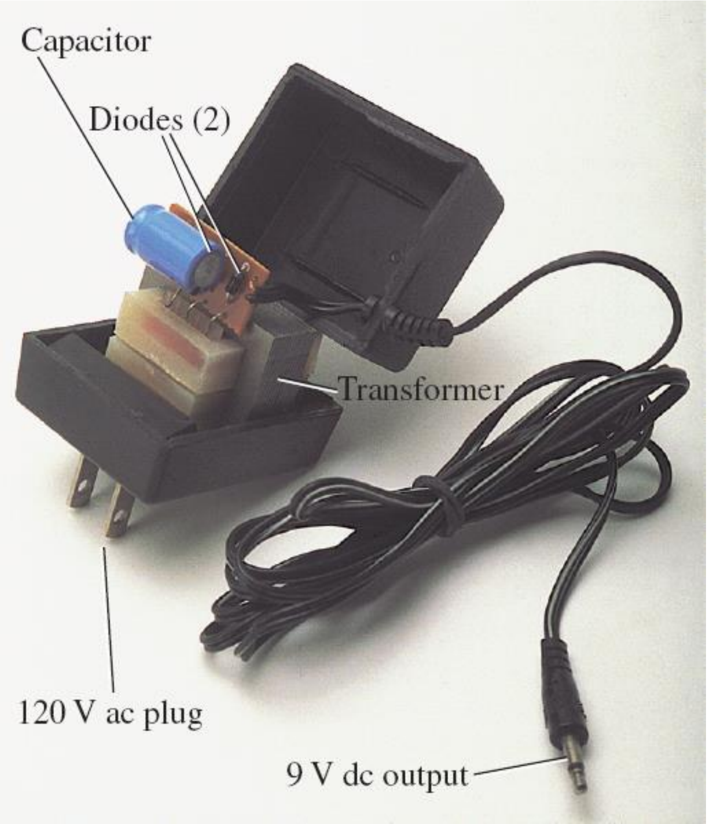


FIG. 2.35 *Internal construction of the 9 V dc supply in Fig. 2.34.*

LOGO

ความต้านทาน

Resistance

INTRODUCTION

- This opposition to the flow of charge through an electrical circuit, called **resistance,** has the units of **ohms** and uses the Greek letter *omega* (Ω) as its symbol.
- The graphic symbol for resistance, which resembles the cutting edge of a saw.

INTRODUCTION

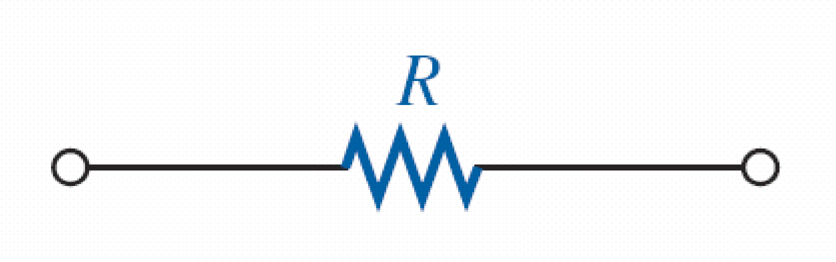


FIG. 3.1 *Resistance symbol and notation.*

LOGO

INTRODUCTION

- This opposition, due primarily to collisions and friction between the free electrons and other electrons, ions, and atoms in the path of motion, converts the supplied electrical energy into **heat** that raises the temperature of the electrical component and surrounding medium.
- The heat you feel from an electrical heater is simply due to current passing through a high-resistance material.

LOGO

RESISTANCE: CIRCULAR WIRES

- The resistance of any material is due primarily to four factors:
  - *Material*
  - *Length*
  - *Cross-sectional area*
  - *Temperature of the material*

LOGO

RESISTANCE: CIRCULAR WIRES

- The first three elements are related by the following basic equation for resistance:

$$R = \rho \frac{l}{A}$$

ρ = CM-Ω/ft at T = 20°C

l = feet

A = area in circular mils (CM)

LOGO

RESISTANCE: CIRCULAR WIRES

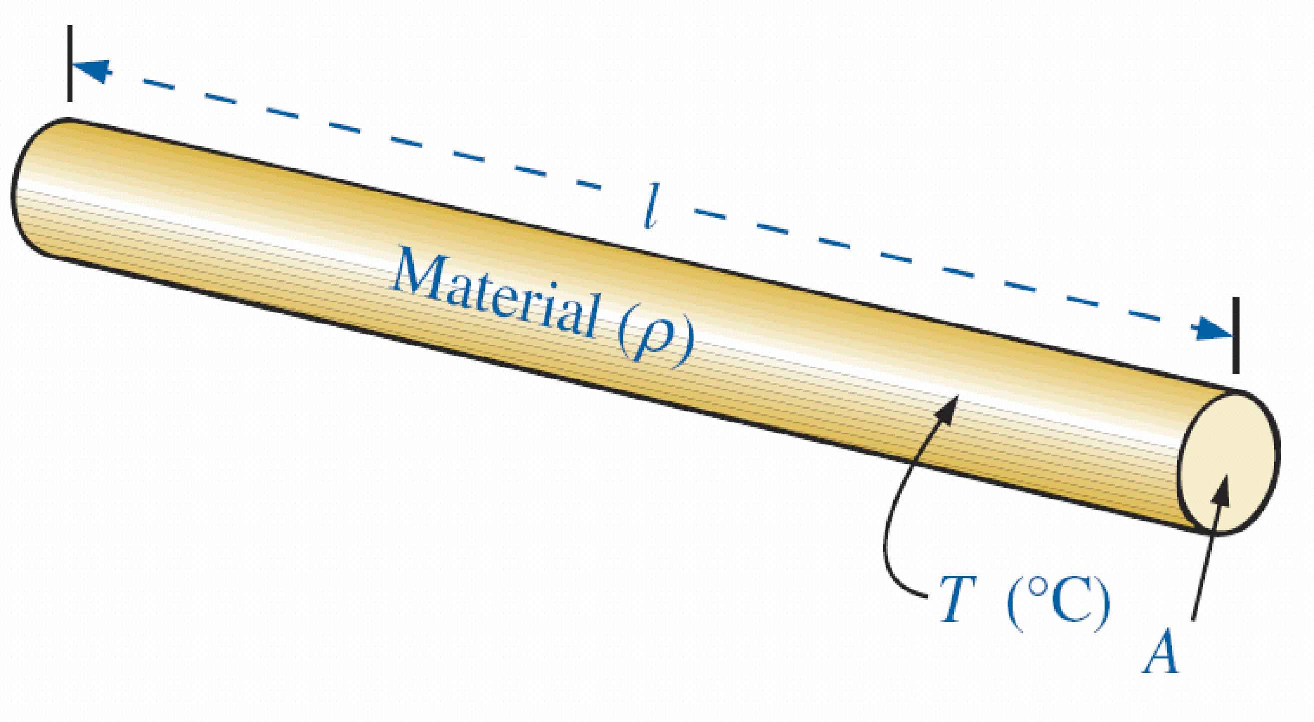


FIG. 3.2 *Factors affecting the resistance of a conductor.*

RESISTANCE: CIRCULAR WIRES

Material	ρ (CM-Ω/ft)@20°C
Silver	9.9
Copper	**10.37**
Gold	14.7
Aluminum	17.0
Tungsten	33.0
Nickel	47.0
Iron	74.0
Constantan	295.0
Nichrome	600.0
Calorite	720.0
Carbon	21,000.0

TABLE 3.1 *Resistivity (p) of various materials.*

LOGO

RESISTANCE: CIRCULAR WIRES

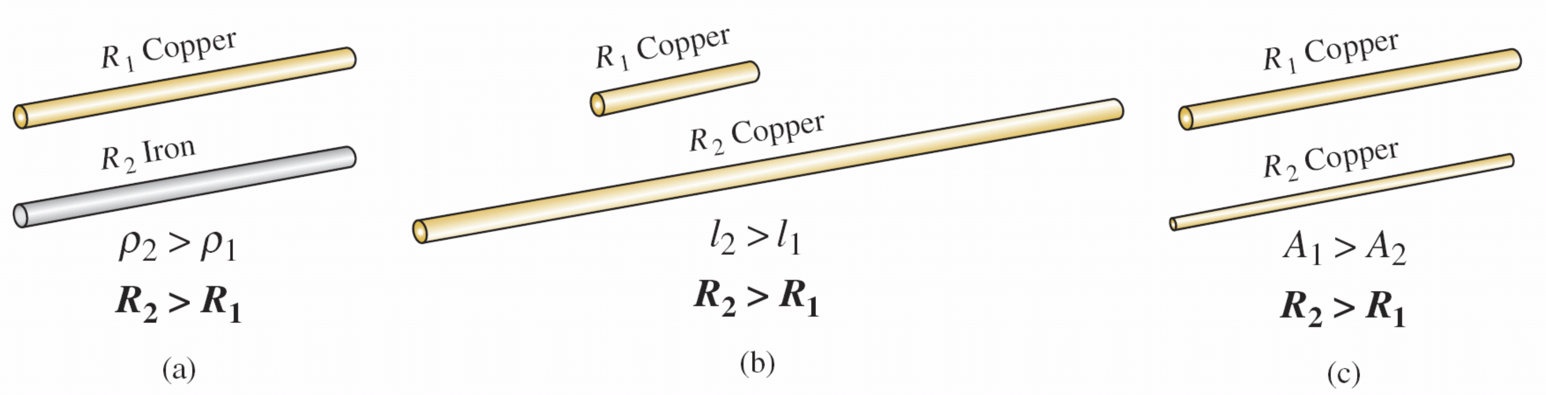


FIG. 3.3 *Cases in which R2 > R1. For each case, all remaining parameters that control the resistance level are the same.*

LOGO

RESISTANCE: CIRCULAR WIRES

Circular Mils (CM)

- In Eq. (3.1), the area is measured in a quantity called **circular mils** (CM).
- It is the quantity used in most commercial wire tables, and thus it needs to be carefully defined.
- The *mil* is a unit of measurement for length and is related to the inch by

$$1 \text{ mil} = \frac{1}{1000} \text{ in.}$$

$$1000 \text{ mils} = 1 \text{ in.}$$

LOGO

WIRE TABLES

- The wire table was designed primarily to standardize the size of wire produced by manufacturers.
- As a result, the manufacturer has a larger market, and the consumer knows that standard wire sizes will always be available.
- The table was designed to assist the user in every way possible; it usually includes data such as the cross-sectional area in circular mils, diameter in mils, ohms per 1000 feet at 20°C, and weight per 1000 feet.

WIRE TABLES

	AWG #	Area (CM)	Ω/1000 ft at 20°C	Maximum Allowable Current for RHW Insulation (A)*
(4/0)	**0000**	211,600	0.0490	**230**
(3/0)	**000**	167,810	0.0618	**200**
(2/0)	**00**	133,080	0.0780	**175**
(1/0)	**0**	105,530	0.0983	**150**
	1	83,694	0.1240	**130**
	2	66,373	0.1563	**115**
	3	52,634	0.1970	**100**
	4	41,742	0.2485	**85**
	5	33,102	0.3133	—
	6	26,250	0.3951	**65**
	7	20,816	0.4982	—
	8	16,509	0.6282	**50**
	9	13,094	0.7921	—
	10	10,381	0.9989	**30**
	11	8,234.0	1.260	—
	12	6,529.9	1.588	**20**
	13	5,178.4	2.003	—
	14	4,106.8	2.525	**15**
	15	3,256.7	3.184	
	16	2,582.9	4.016	
	17	2,048.2	5.064	
	18	1,624.3	6.385	
	19	1,288.1	8.051	
	20	1,021.5	10.15	
	21	810.10	12.80	
	22	642.40	16.14	
	23	509.45	20.36	
	24	404.01	25.67	
	25	320.40	32.37	
	26	254.10	40.81	
	27	201.50	51.47	
	28	159.79	64.90	
	29	126.72	81.83	
	30	100.50	103.2	
	31	79.70	130.1	
	32	63.21	164.1	
	33	50.13	206.9	
	34	39.75	260.9	
	35	31.52	329.0	
	36	25.00	414.8	
	37	19.83	523.1	
	38	15.72	659.6	
	39	12.47	831.8	
	40	9.89	1049.0	

TABLE 3.2 *American Wire Gage (AWG) sizes.*

LOGO

WIRE TABLES

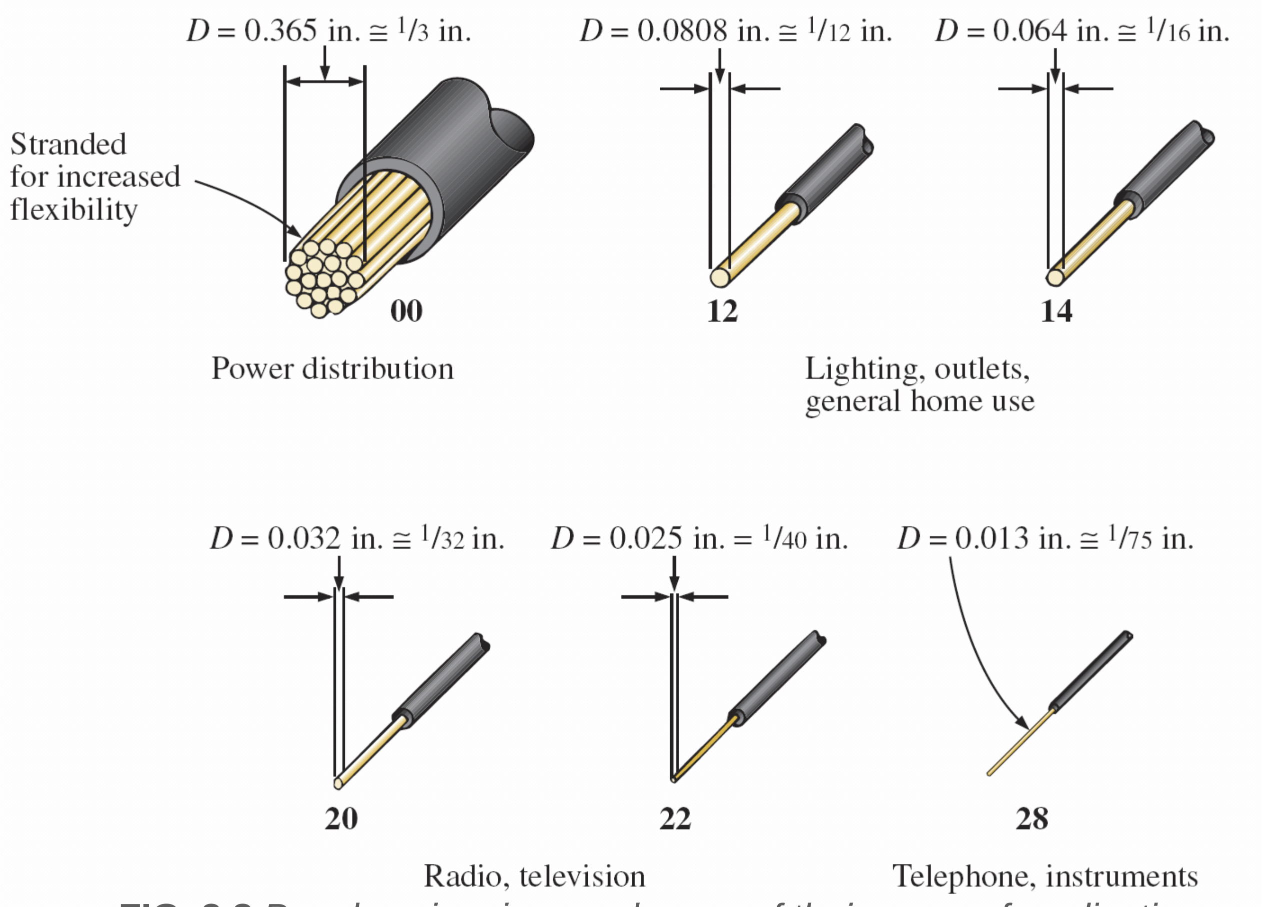


FIG. 3.8 *Popular wire sizes and some of their areas of application.*

LOGO

TYPES OF RESISTORS

Fixed Resistors

- Resistors are made in many forms, but all belong in either of two groups: fixed or variable.
- The most common of the low-wattage, fixedtype resistors is the film resistor.

TYPES OF RESISTORS

Fixed Resistors

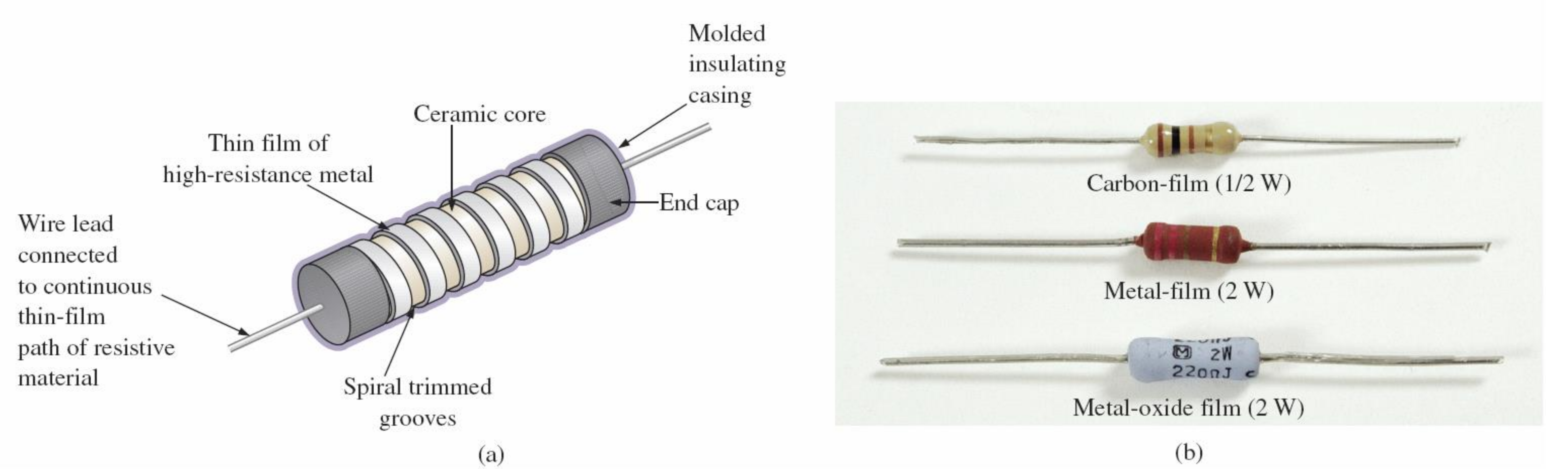


FIG. 3.12 *Film resistors: (a) construction; (b) types.*

LOGO

TYPES OF RESISTORS

Fixed Resistors

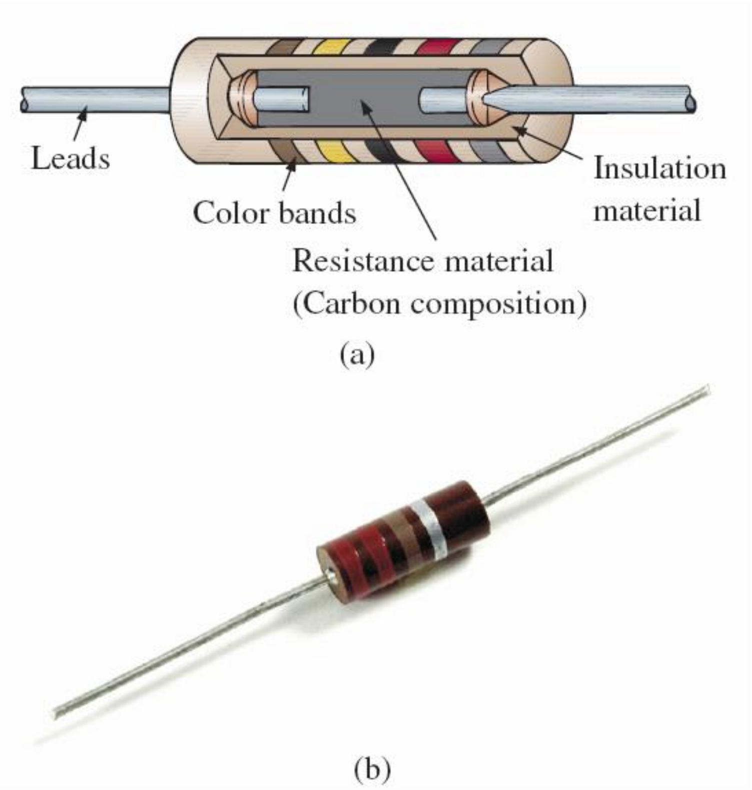


FIG. 3.13 *Fixed-composition resistors: (a) construction; (b) appearance.*

LOGO

TYPES OF RESISTORS

Fixed Resistors

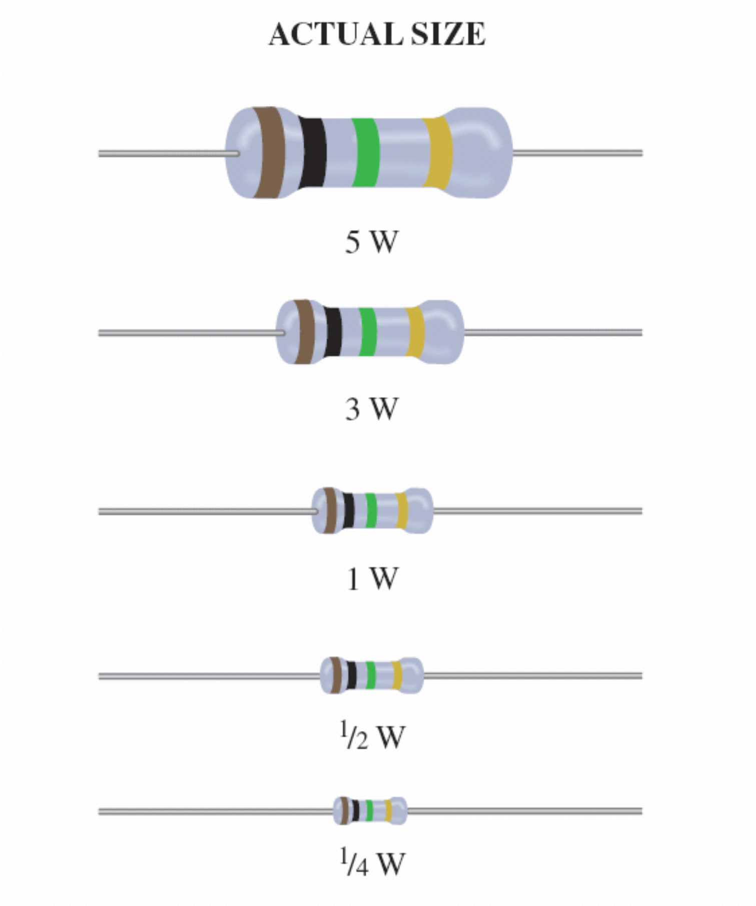


FIG. 3.14 *Fixed metal-oxide resistors of different wattage ratings.*

LOGO

TYPES OF RESISTORS

Fixed Resistors

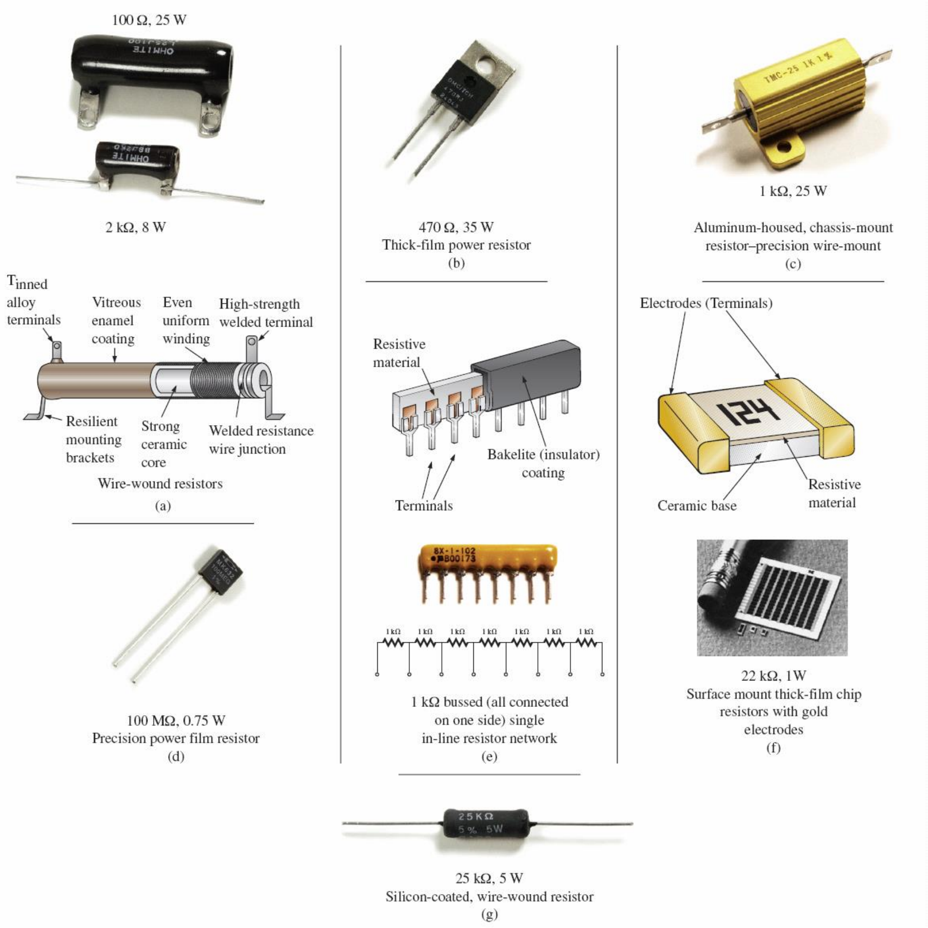


FIG. 3.15 *Various types of fixed resistors.*

LOGO

TYPES OF RESISTORS

Variable Resistors

- Variable resistors, as the name implies, have a terminal resistance that can be varied by turning a dial, knob, screw, or whatever seems appropriate for the application.
- They can have two or three terminals, but most have three terminals. If the two- or three-terminal device is used as a variable resistor, it is usually referred to as a **rheostat.**

LOGO

TYPES OF RESISTORS

Variable Resistors

- If the three-terminal device is used for controlling potential levels, it is then commonly called a **potentiometer.**
- Even though a three-terminal device can be used as a rheostat or a potentiometer (depending on how it is connected), it is typically called a *potentiometer* when listed in trade magazines or requested for a particular application.

LOGO

TYPES OF RESISTORS

Variable Resistors

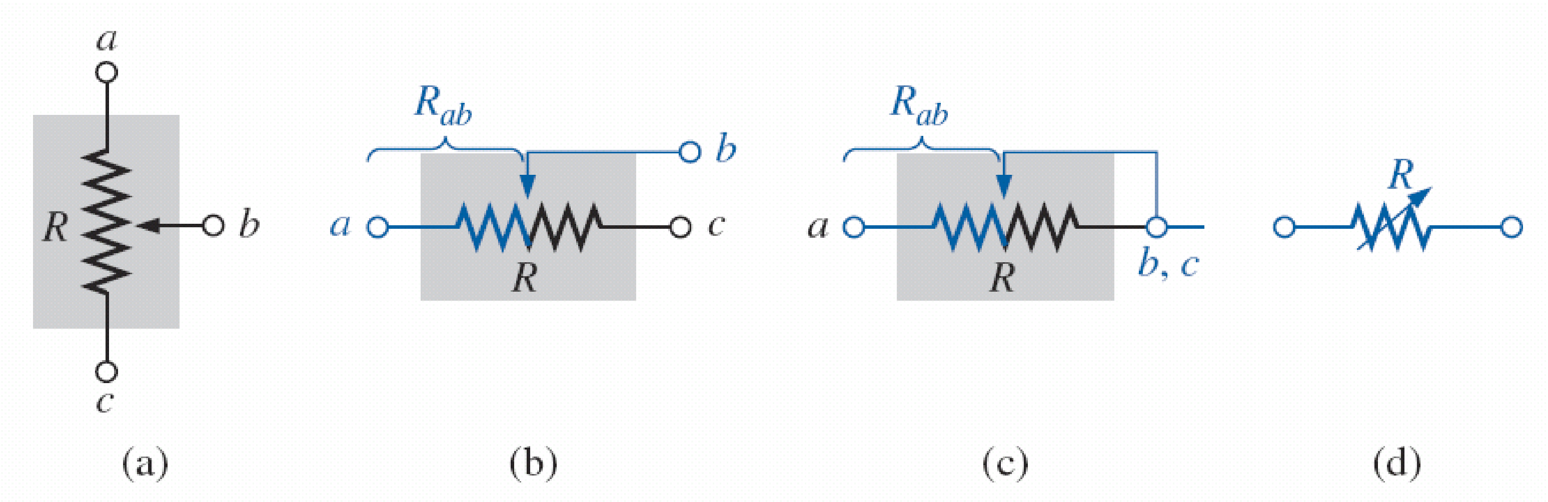


FIG. 3.16 *Potentiometer: (a) symbol; (b) and (c) rheostat connections; (d) rheostat symbol.*

LOGO

TYPES OF RESISTORS

Variable Resistors

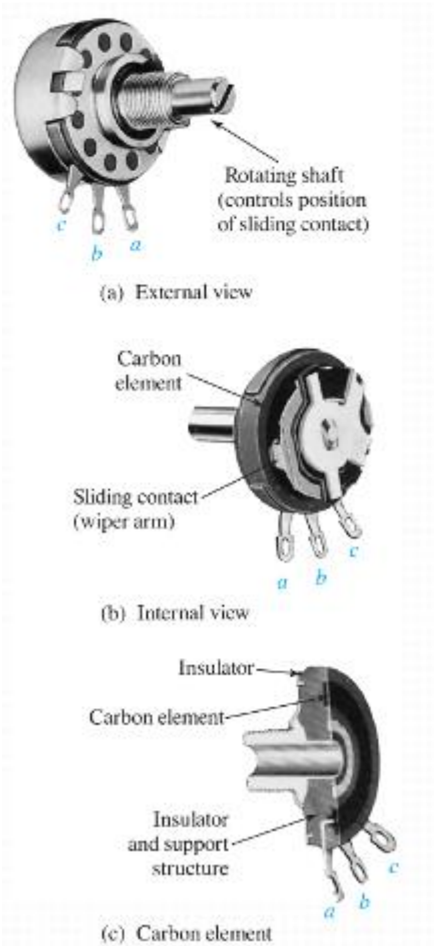


FIG. 3.17 *Molded composition-type potentiometer.* (Courtesy of Allen-Bradley Co.)

LOGO

TYPES OF RESISTORS

Variable Resistors

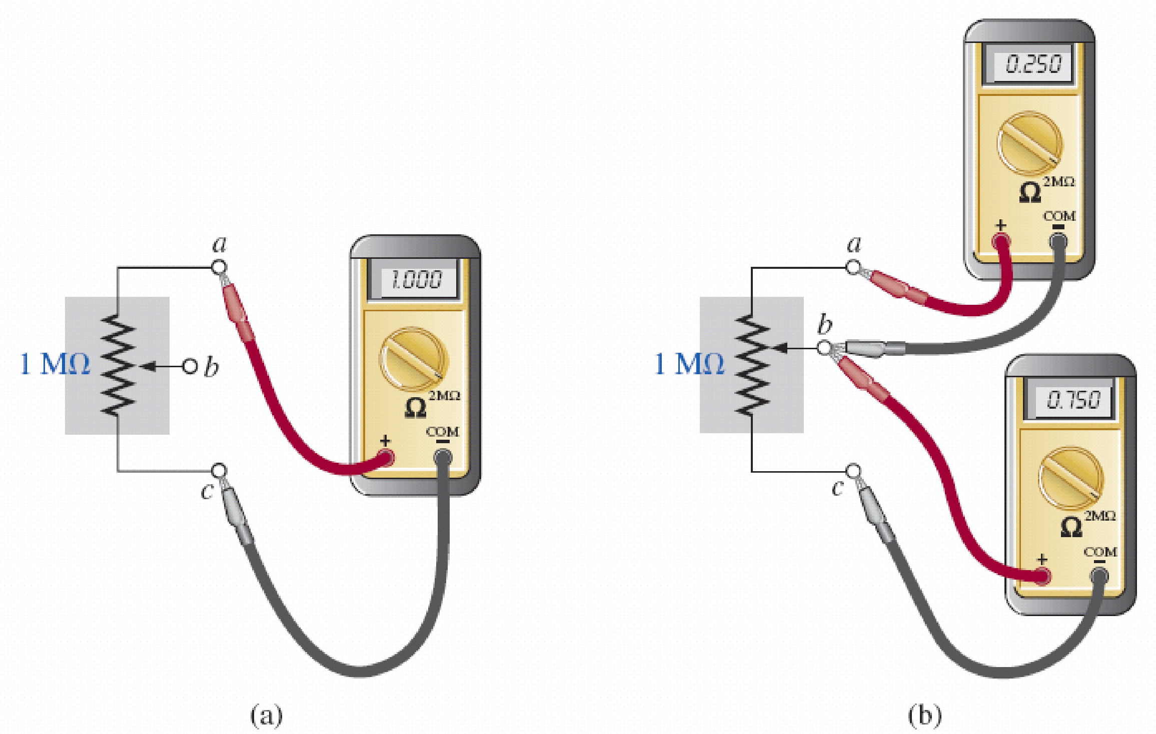


FIG. 3.18 *Resistance components of a potentiometer: (a) between outside terminals; (b) between wiper arm and each outside terminal.*

LOGO

TYPES OF RESISTORS

Variable Resistors

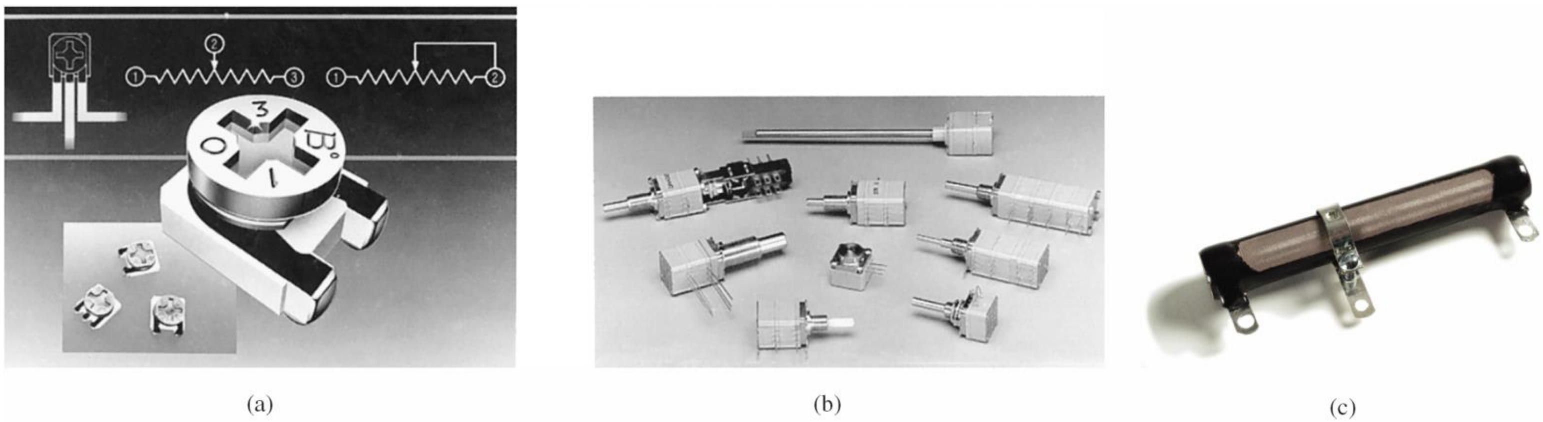


FIG. 3.19 *Variable resistors: (a) 4 mm (5/32 in.) trimmer (courtesy of Bourns, Inc.); (b) conductive plastic and cermet elements (courtesy of Honeywell Clarostat); (c) three-point wire-wound resistor.*

LOGO

COLOR CODING AND STANDARD RESISTOR VALUES

- A wide variety of resistors, fixed or variable, are large enough to have their resistance in ohms printed on the casing.
- Some, however, are too small to have numbers printed on them, so a system of **color coding** is used.
- For the thin-film resistor, four, five, or six bands may be used.
- The four-band scheme is described.
- Later in this section the purpose of the fifth and sixth bands will be described.

LOGO

COLOR CODING AND STANDARD RESISTOR VALUES

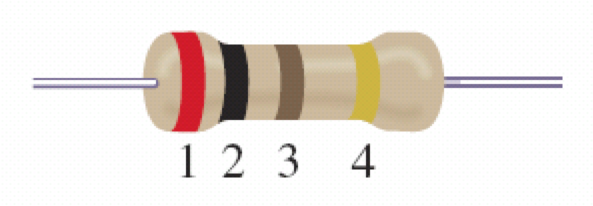


FIG. 3.21 *Color coding for fixed resistors.*

LOGO

COLOR CODING AND STANDARD RESISTOR VALUES

Number	Color
0	Black
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Gray
9	White
±5% (0.1 multiplier if 3rd band)	Gold
±10% (0.01 multiplier if 3rd band)	Silver

FIG. 3.22 *Color coding.*

LOGO

COLOR CODING AND STANDARD RESISTOR VALUES

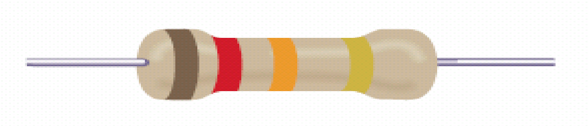


FIG. 3.23 *Example 3.11.*

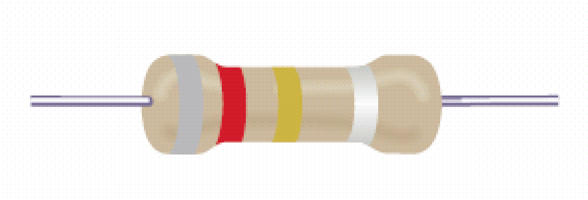


FIG. 3.24 *Example 3.12.*

LOGO

COLOR CODING AND STANDARD RESISTOR VALUES

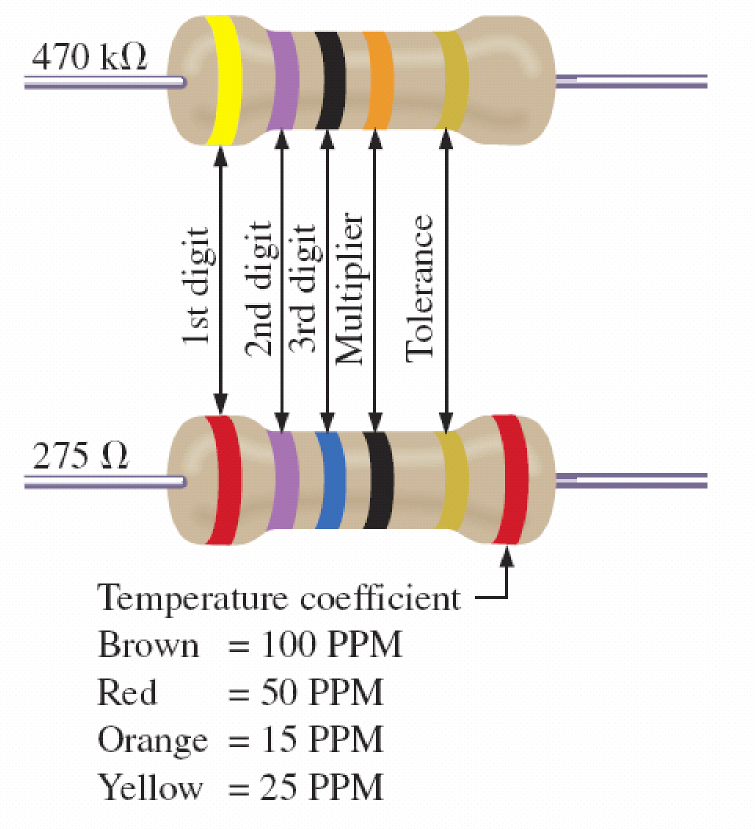


FIG. 3.25 *Five-band color coding for fixed resistors.*

LOGO

COLOR CODING AND STANDARD RESISTOR VALUES

Ohms (Ω)					Kilohms (kΩ)		Megohms (MΩ)	
0.10	**1.0**	**10**	**100**	**1000**	**10**	**100**	**1.0**	**10.0**
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	**1.2**	**12**	**120**	**1200**	**12**	**120**	**1.2**	**12.0**
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	**1.5**	**15**	**150**	**1500**	**15**	**150**	**1.5**	**15.0**
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	**1.8**	**18**	**180**	**1800**	**18**	**180**	**1.8**	**18.0**
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	**2.2**	**22**	**220**	**2200**	**22**	**220**	**2.2**	**22.0**
0.24	2.4	24	240	2400	24	240	2.4	
0.27	**2.7**	**27**	**270**	**2700**	**27**	**270**	**2.7**	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	**3.3**	**33**	**330**	**3300**	**33**	**330**	**3.3**	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	**3.9**	**39**	**390**	**3900**	**39**	**390**	**3.9**	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	**4.7**	**47**	**470**	**4700**	**47**	**470**	**4.7**	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	**5.6**	**56**	**560**	**5600**	**56**	**560**	**5.6**	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	**6.8**	**68**	**680**	**6800**	**68**	**680**	**6.8**	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	**8.2**	**82**	**820**	**8200**	**82**	**820**	**8.2**	
0.91	9.1	91	910	9100	91	910	9.1	

TABLE 3.5 *Standard values of commercially available resistors.*

CONDUCTANCE

- By finding the reciprocal of the resistance of a material, we have a measure of how well the material conducts electricity.
- The quantity is called **conductance,** has the symbol *G*, and is measured in *siemens*.

OHMMETERS

- The **ohmmeter** is an instrument used to perform the following tasks and several other useful functions:
  - *Measure the resistance of individual or combined elements.*
  - *Detect open-circuit (high-resistance) and short-circuit (lowresistance) situations.*
  - *Check the continuity of network connections and identify wires of a multilead cable.*
  - *Test some semiconductor (electronic) devices.*

LOGO

OHMMETERS

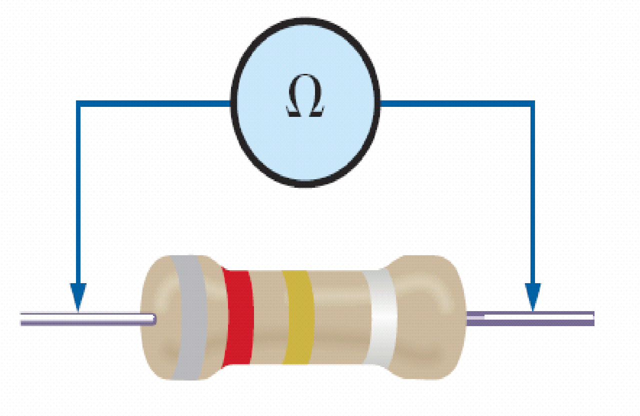


FIG. 3.28 *Measuring the resistance of a single element.*

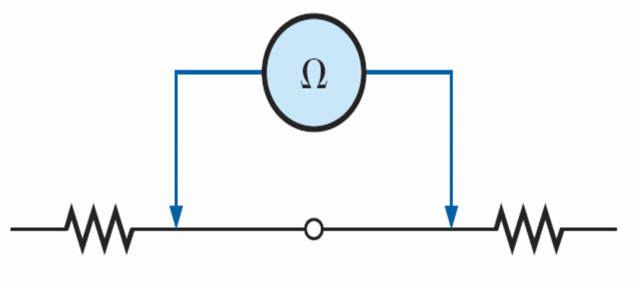


FIG. 3.29 *Checking the continuity of a connection.*

LOGO

OHMMETERS

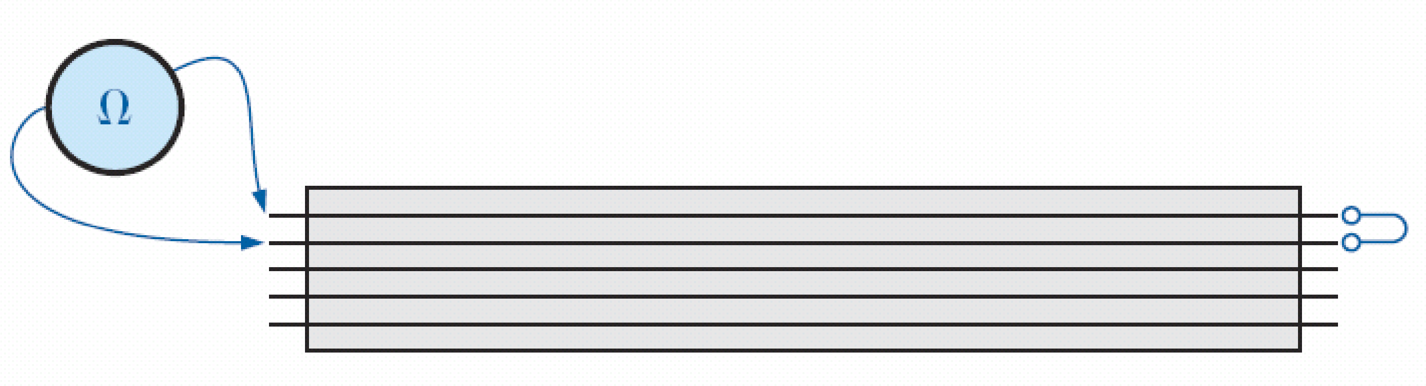


FIG. 3.30 *Identifying the leads of a multilead cable.*

LOGO

SUPERCONDUCTORS

- The field of electricity/electronics is one of the most exciting of our time.
- New developments appear almost weekly from extensive research and development activities.
- The research drive to develop a superconductor capable of operating at temperatures closer to room temperature has been receiving increasing attention in recent years due to the need to cut energy losses.
  - What are superconductors?
  - Why is their development so important?
  - In a nutshell, ***superconductors are conductors of electric charge that, for all practical purposes, have zero resistance.***

LOGO

SUPERCONDUCTORS

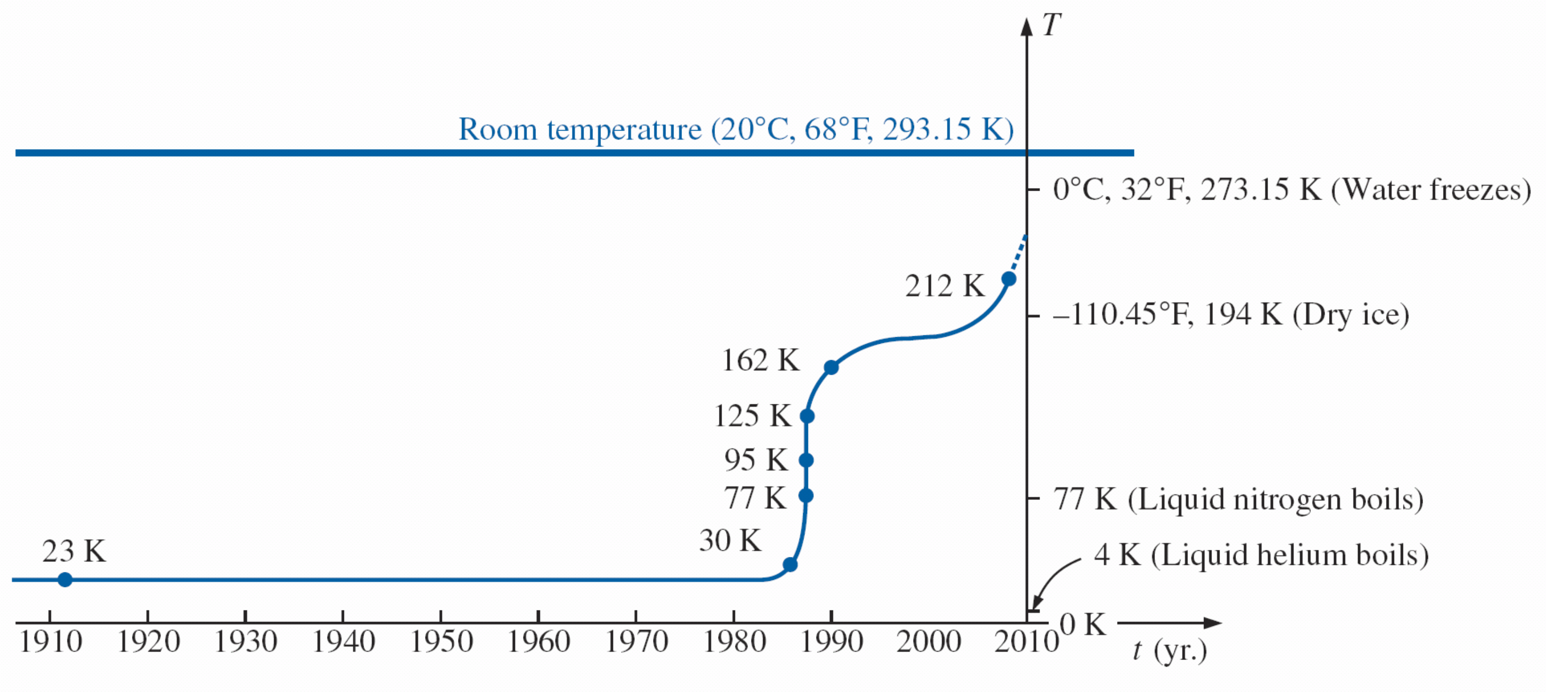


FIG. 3.34 *Rising temperatures of superconductors.*

LOGO

SUPERCONDUCTORS

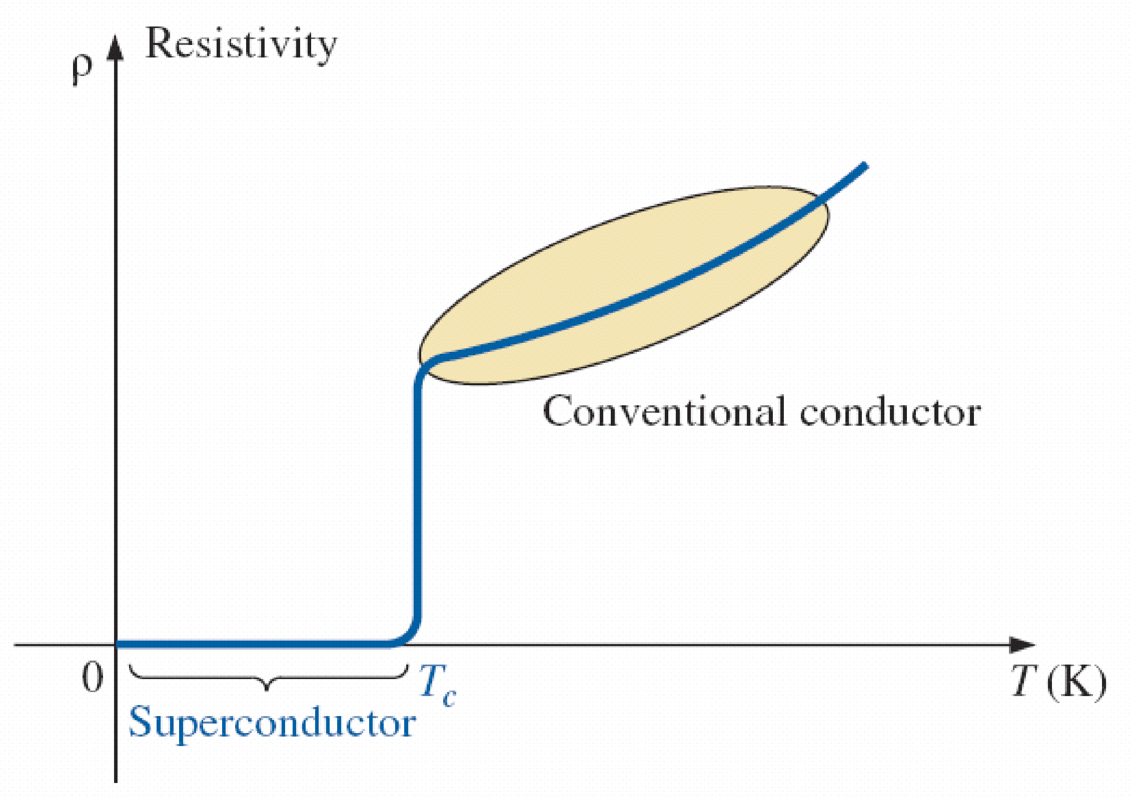


FIG. 3.35 *Defining the critical temperature T_c.*

THERMISTORS

- The **thermistor** is a two-terminal semiconductor device whose resistance, as the name suggests, is temperature sensitive.

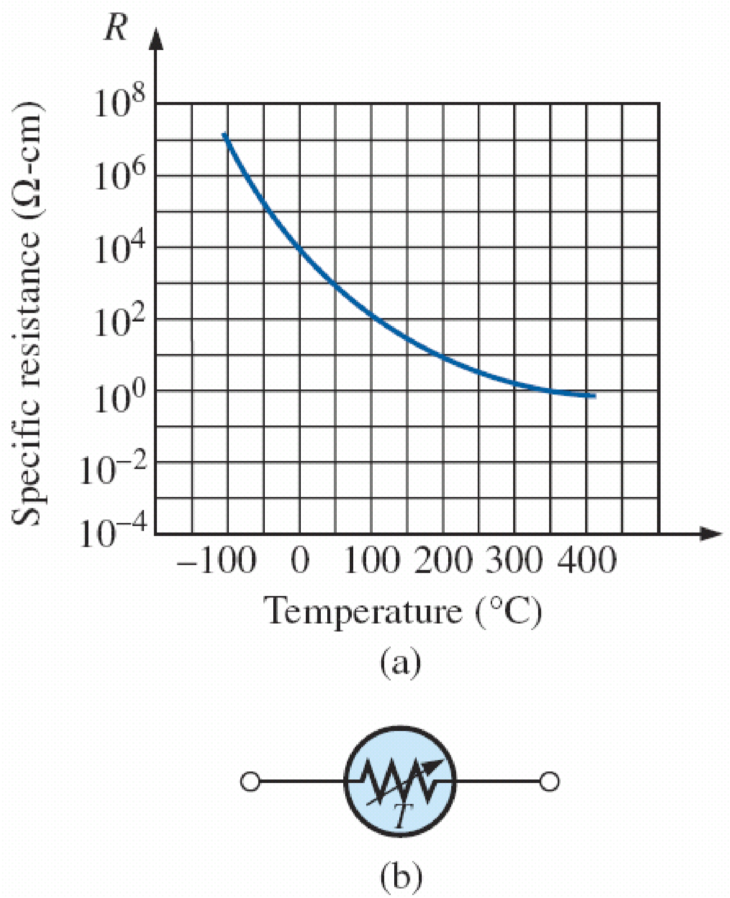


FIG. 3.36 *Thermistor: (a) characteristics; (b) symbol.*

LOGO

THERMISTORS

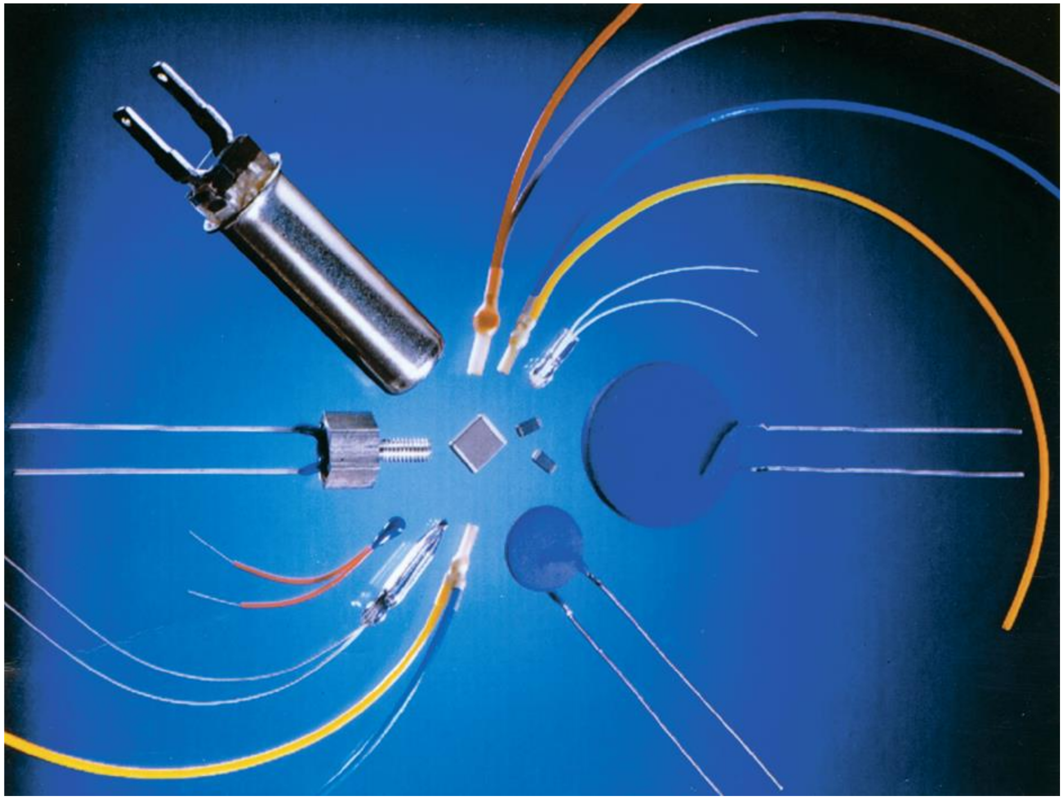


FIG. 3.37 *NTC (negative temperature coefficient) and PTC (positive temperature coefficient) thermistors.*

LOGO

THERMISTORS

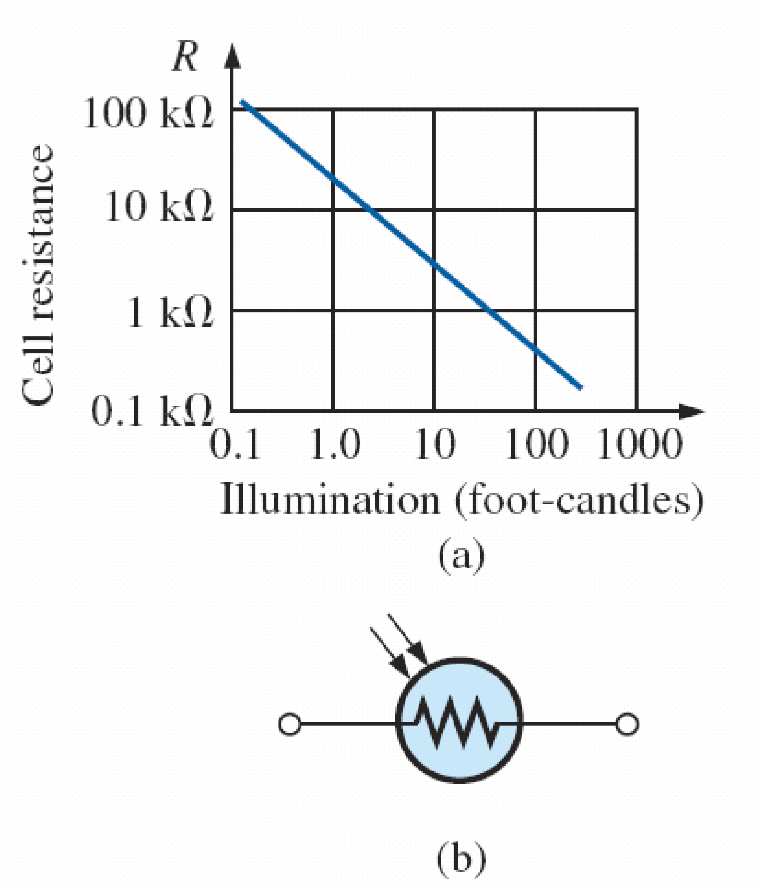


FIG. 3.38 *Photoconductive cell: (a) characteristics. (b) symbol.*

LOGO

PHOTOCONDUCTIVE CELL

- The **photoconductive cell** is a two-terminal semiconductor device whose terminal resistance is determined by the intensity of the incident light on its exposed surface.
- As the applied illumination increases in intensity, the energy state of the surface electrons and atoms increases, with a resultant increase in the number of “free carriers” and a corresponding drop in resistance.

LOGO

PHOTOCONDUCTIVE CELL

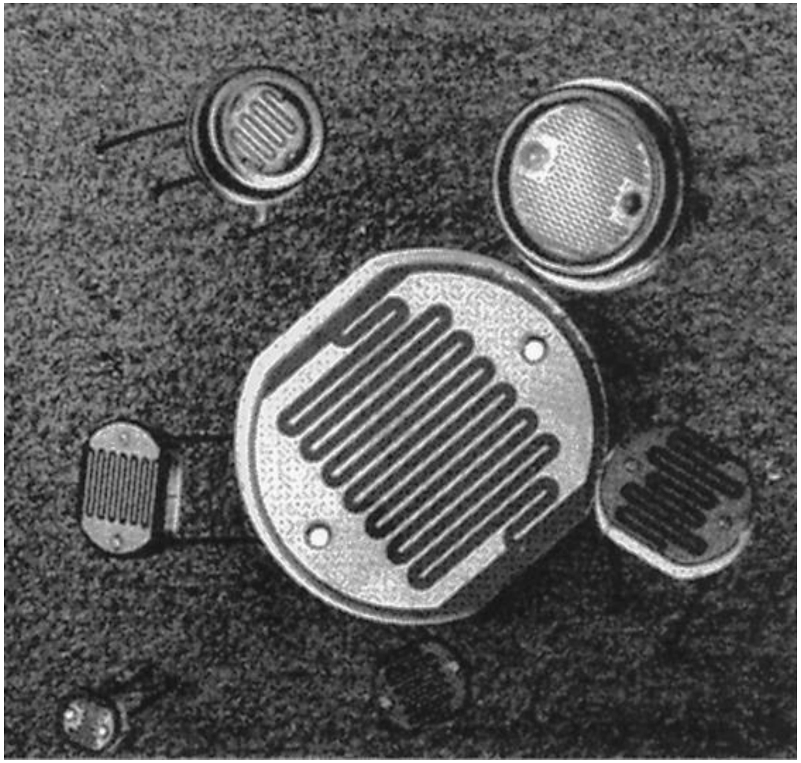


FIG. 3.39 *Photoconductive cells.*

LOGO

VARISTORS

- **Varistors** are voltage-dependent, nonlinear resistors used to suppress high-voltage transients; that is, their characteristics enable them to limit the voltage that can appear across the terminals of a sensitive device or system.

VARISTORS

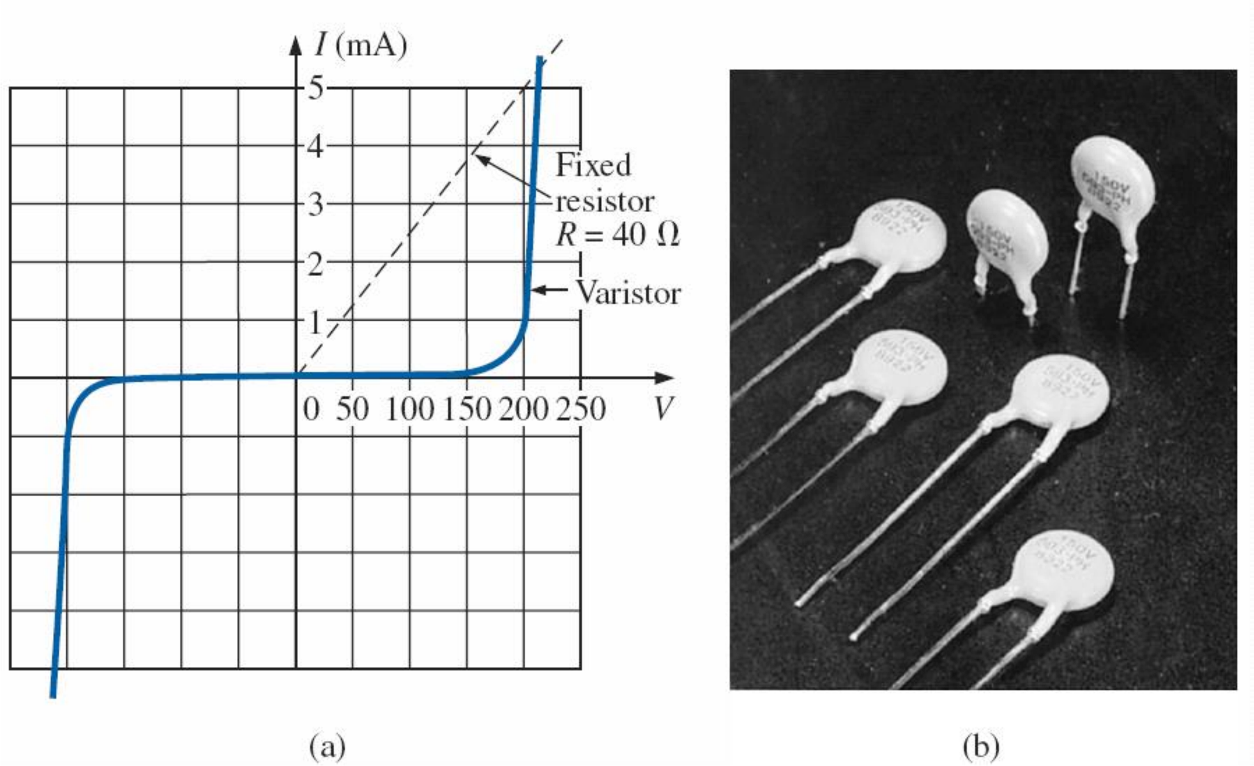


FIG. 3.40 *Varistors available with maximum dc voltage ratings between 18 V and 615 V.*

LOGO

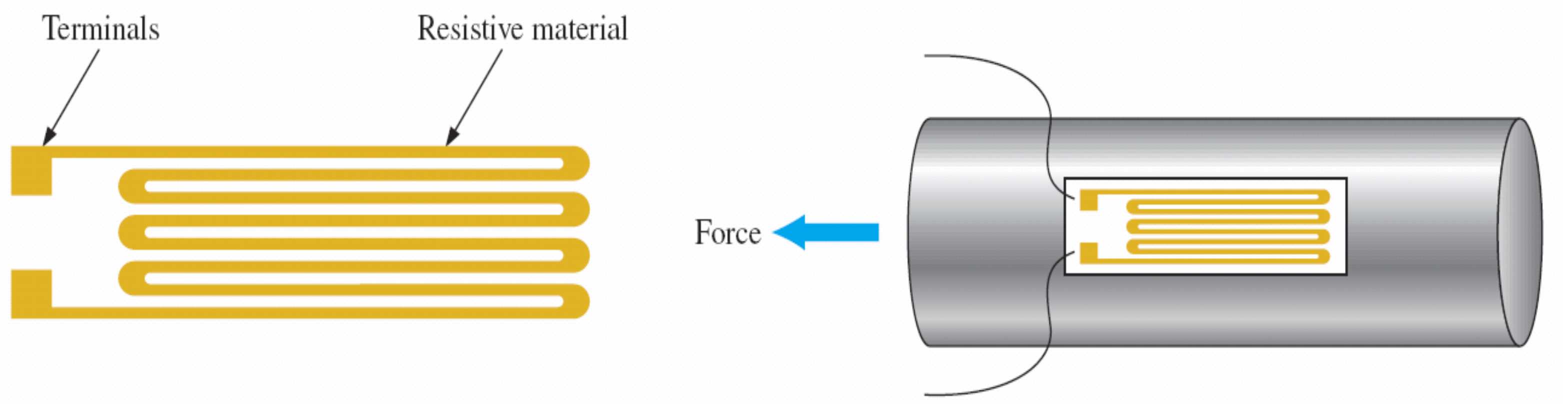
APPLICATIONS

- The following are examples of how resistance can be used to perform a variety of tasks, from heating to measuring the stress or strain on a supporting member of a structure.
- In general, resistance is a component of every electrical or electronic application.

APPLICATIONS

Strain Gauges

- Any change in the shape of a structure can be detected using strain gauges whose resistance changes with applied stress or flex.



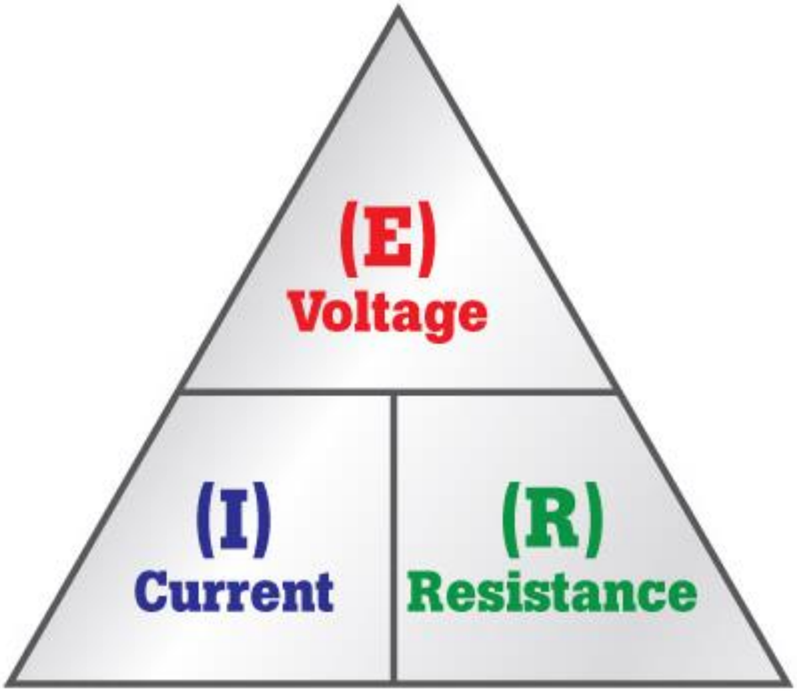
(a) Typical strain gauge configuration.

(b) The strain gauge is bonded to the surface to be measured along the line of force. When the surface lengthens, the strain gauge stretches.

FIG. 3.43 *Resistive strain gauge.*

LOGO

OHM'S LAW



$$I = \frac{E}{R}$$ (amperes, A)

$$E = IR$$ (volts, V)

$$R = \frac{E}{I}$$ (ohms, Ω)

LOGO

OHM'S LAW

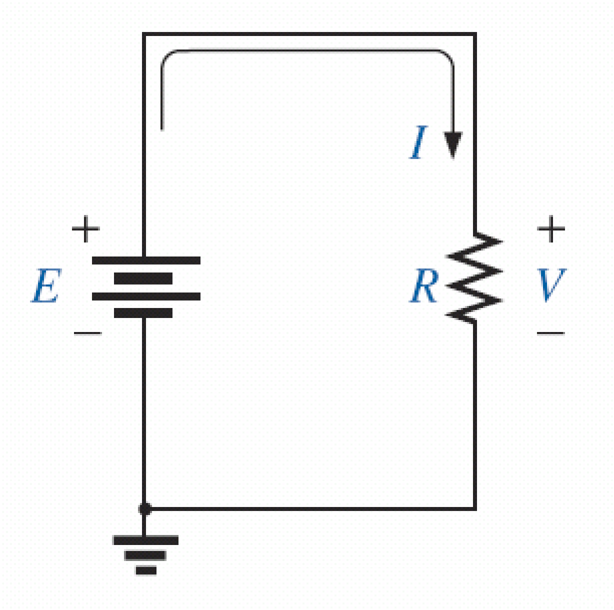


FIG. 4.2 *Basic circuit.*

LOGO

OHM'S LAW

$$I = \frac{V_R}{R} = \frac{E}{R}$$

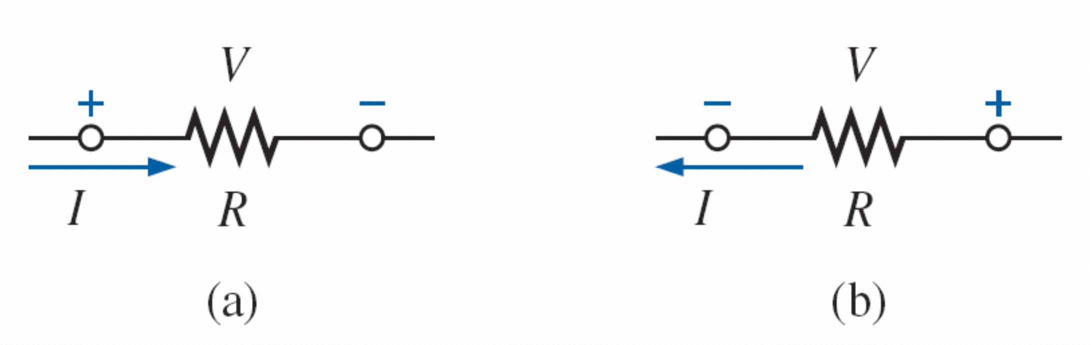


FIG. 4.3 *Defining polarities.*

LOGO

OHM'S LAW

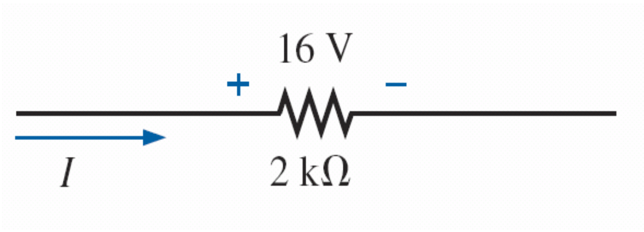


FIG. 4.4 *Example 4.3.*

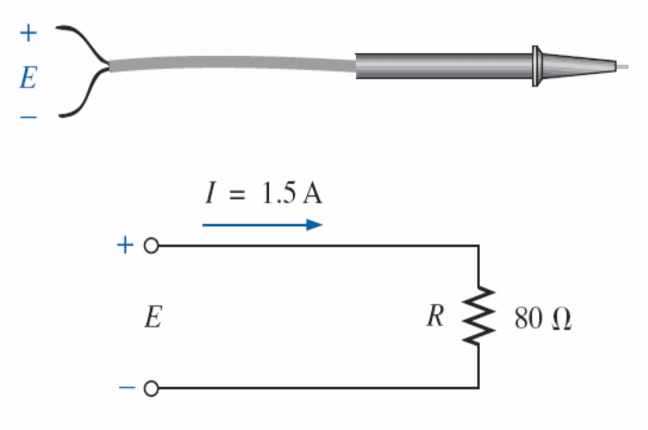


FIG. 4.5 *Example 4.4.*

LOGO

PLOTTING OHM'S LAW

- Graphs, characteristics, plots, and the like play an important role in every technical field as modes through which the broad picture of the behavior or response of a system can be conveniently displayed.
- It is therefore critical to develop the skills necessary both to read data and to plot them in such a manner that they can be interpreted easily.

LOGO

PLOTTING OHM'S LAW

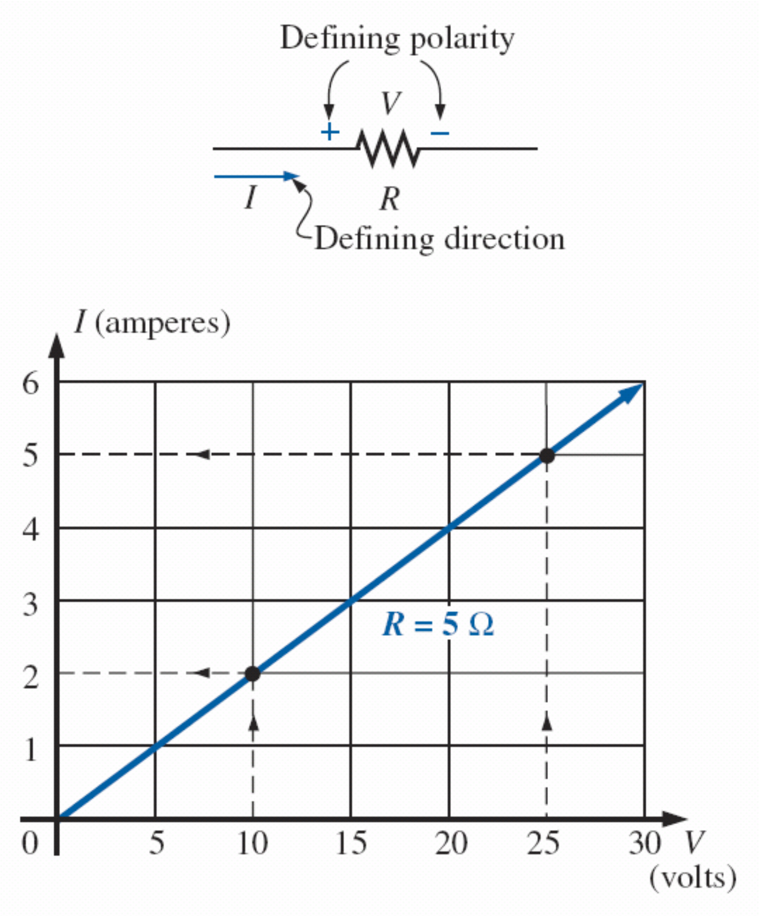


FIG. 4.6 *Plotting Ohm's law.*

LOGO

PLOTTING OHM'S LAW

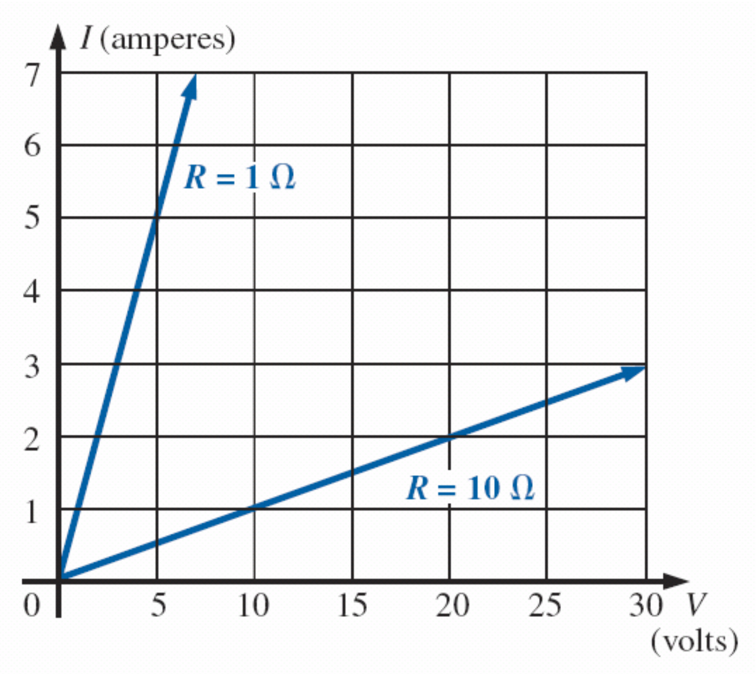


FIG. 4.7 *Demonstrating on an I-V plot that the lower the resistance, the steeper is the slope.*

LOGO

PLOTTING OHM'S LAW

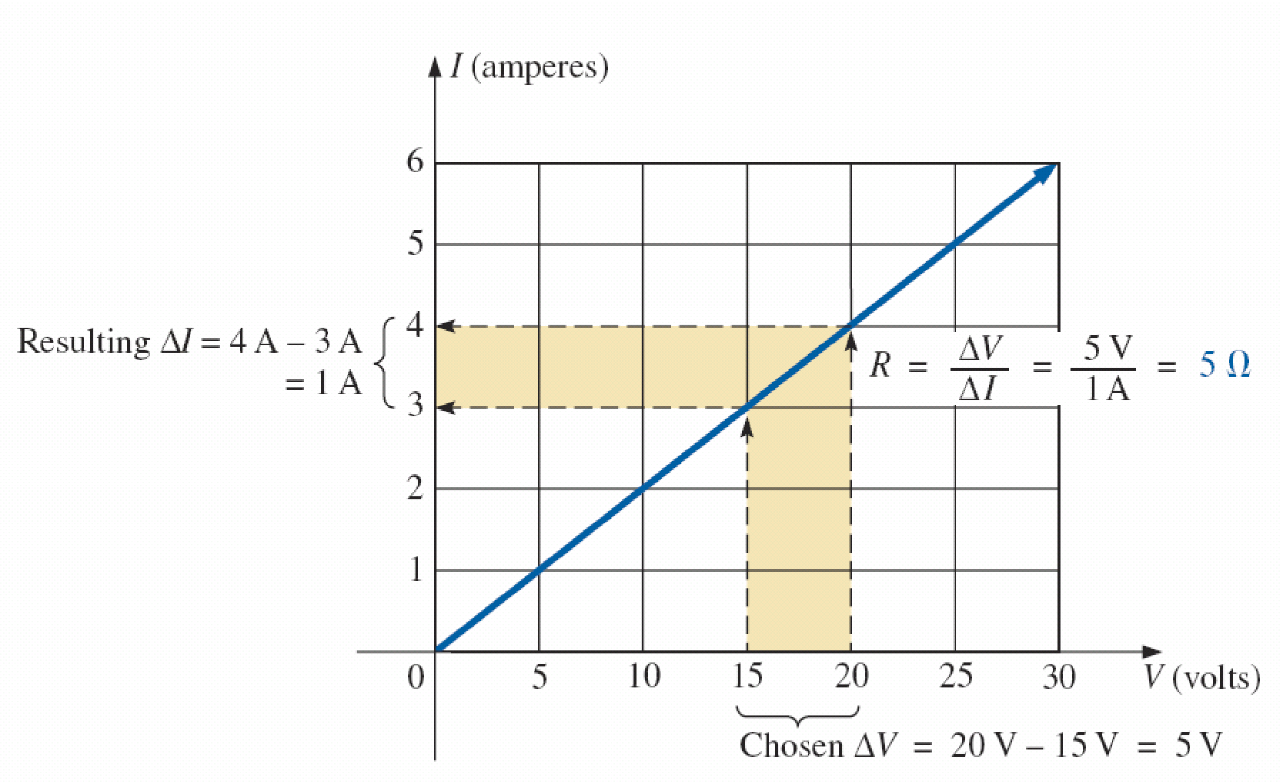


FIG. 4.8 *Applying Eq. (4.7).*

LOGO

PLOTTING OHM'S LAW

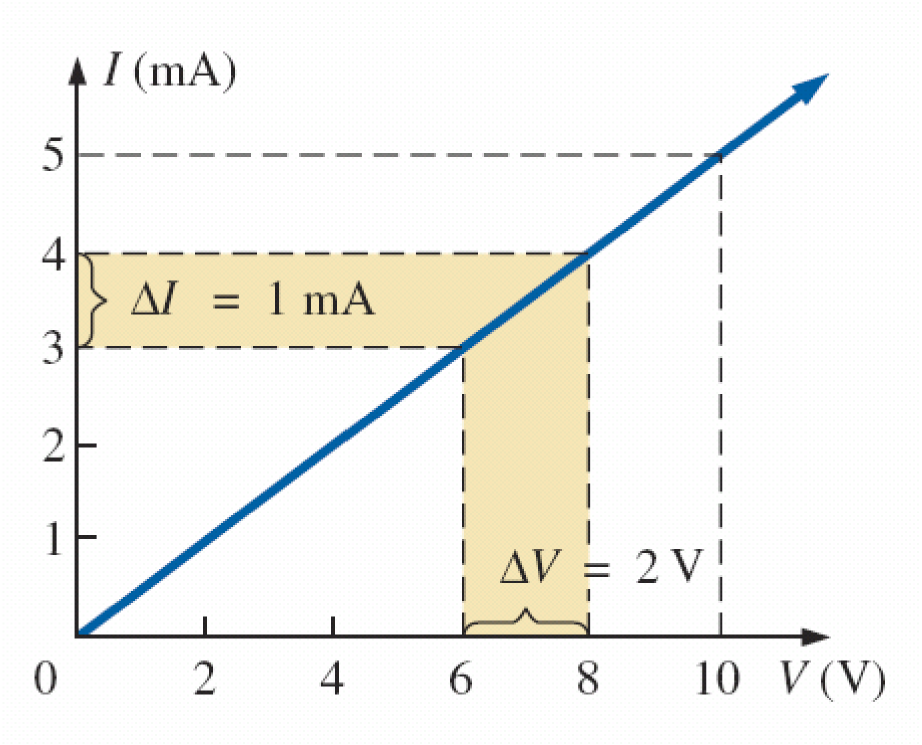


FIG. 4.9 *Example 4.5.*

LOGO

POWER

- In general, *the term power is applied to provide an indication of how much work (energy conversion) can be accomplished in a specified amount of time; that is, power is a rate of doing work.*

ENERGY

$$\text{Energy (Wh)} = \text{power (W)} \times \text{time (h)}$$

$$\text{Energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1000}$$

LOGO

ENERGY

- Note that the energy in kilowatthours is simply the energy in watthours divided by 1000.
- To develop some sense for the kilowatthour energy level, consider that *1 kWh is the energy dissipated by a 100 W bulb in 10 h.*
- The **kilowatthour meter** is an instrument for measuring the energy supplied to the residential or commercial user of electricity.

ENERGY

FIG. 4.16 *Kilowatthour meters: (a) analog; (b) digital.* (Courtesy of ABB Electric Metering Systems.)

ENERGY

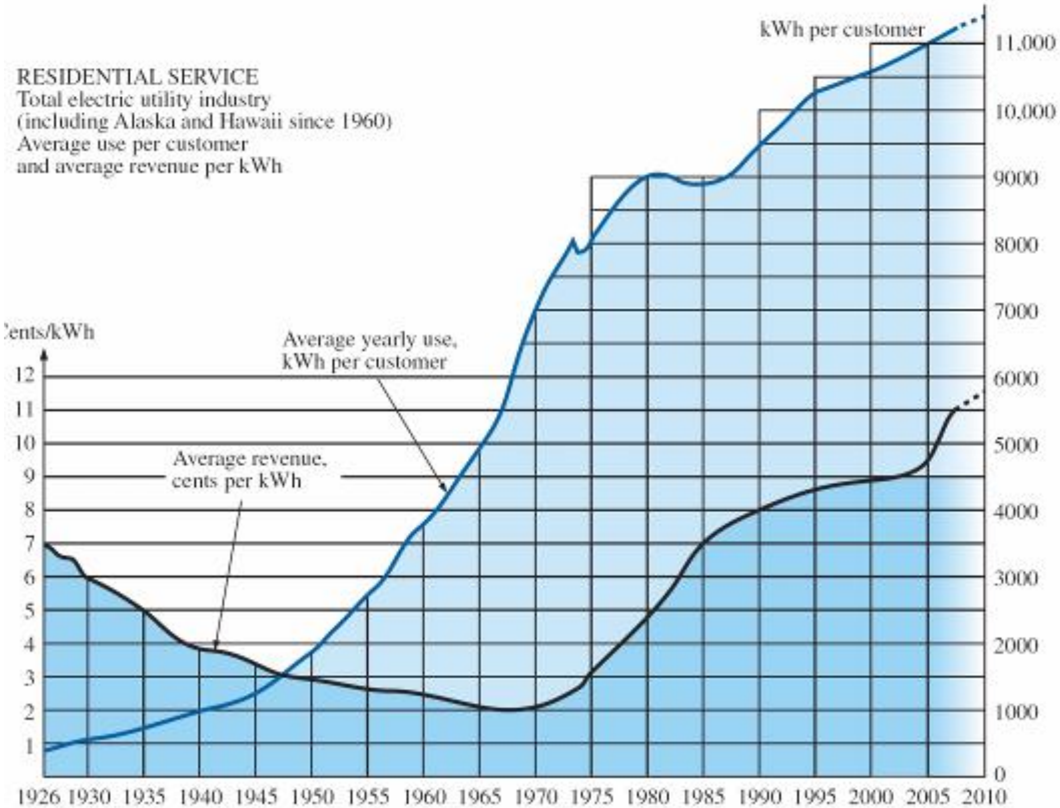


FIG. 4.17 *Cost per kWh and average kWh per customer versus time.* (Based on data from Edison Electric Institute.)

LOGO

ENERGY

Appliance	Wattage Rating	Appliance	Wattage Rating
Air conditioner		Laptop computer:	
(room)	1400	Sleep	<1 (typically 0.3 to 0.5)
Blow dryer	1300	Average use	78
Cellular phone:		Microwave oven	1200
Standby	≅35 mW	Nintendo Wii	19
Talk	≅4.3 W	Radio	70
Clock	2	Range (self-cleaning)	12,200
Clothes dryer		Refrigerator	
(electric)	4300	(automatic defrost)	1800
Coffee maker	900	Shaver	15
Dishwasher	1200	Sun lamp	280
Fan:		Toaster	1200
Portable	90	Trash compactor	400
Window	200	TV:	
Heater	1500	Plasma	340
Heating equipment:		LCD	220
Furnace fan	320	VCR/DVD	25
Oil-burner motor	230	Washing machine	500
Iron, dry or steam	1000	Water heater	4500
		Xbox 360	187

TABLE 4.1 *Typical wattage ratings of some common household items.*

LOGO

Thank You !