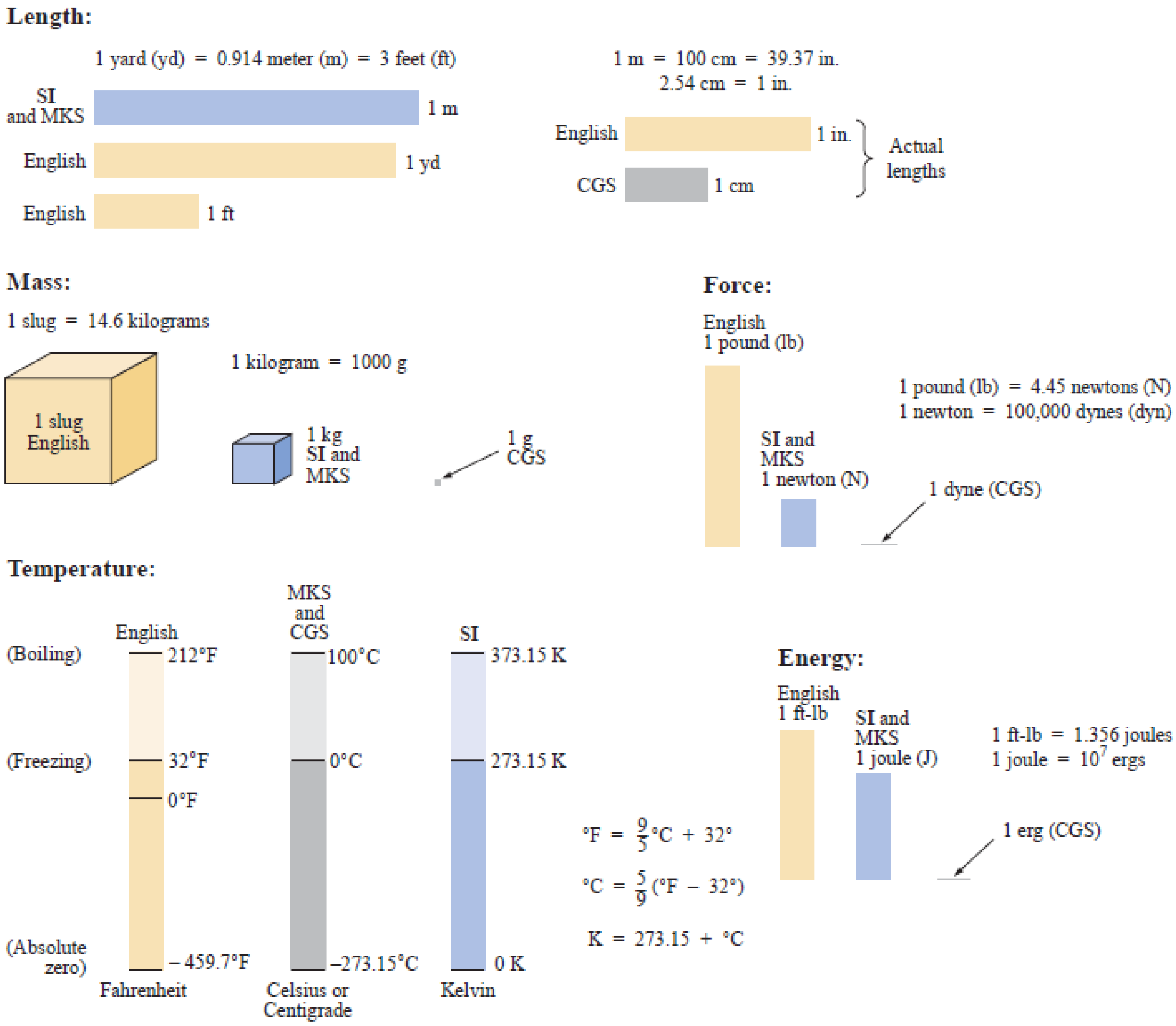
1.1 SYSTEMS OF UNITS

In the past, the *systems of units* most commonly used were the English and metric, as outlined in Table below. Note that while the English system is based on a single standard, the metric is subdivided into two interrelated standards: the MKS and the CGS.

Comparison of the English and metric systems of units.

English	Metric		
	MKS	CGS	SI
Length: Yard (yd) (0.914 m)	Meter (m) (39.37 in.) (100 cm)	Centimeter (cm) (2.54 cm = 1 in.)	**Meter (m)**
Mass: **Slug** (14.6 kg)	Kilogram (kg) (1000 g)	Gram (g)	**Kilogram (kg)**
Force: **Pound** (lb) (4.45 N)	Newton (N) (100,000 dynes)	Dyne	**Newton (N)**
Temperature: Fahrenheit (°F) $\left(= \frac{9}{5}°C + 32\right)$	Celsius or Centigrade (°C) $\left(= \frac{5}{9}(°F - 32)\right)$	Centigrade (°C)	**Kelvin (K)** K = 273.15 + °C
Energy: Foot-pound (ft-lb) (1.356 joules)	Newton-meter (N•m) or joule (J) (0.7376 ft-lb)	Dyne-centimeter or erg (1 joule = 10^7 ergs)	**Joule (J)**
Time: Second (s)	Second (s)	Second (s)	**Second (s)**

The International Bureau of Weights and Measures located at Sevres, France, has been the host for the General Conference of Weights and Measures, and attended by representatives from all nations of the world. In 1960, the General Conference adopted a system called Le Systems International unites (International System of Units), which has the international abbreviation **SI.** Since then, it has been adopted by the Institute of Electrical and Electronic Engineers, Inc. (IEEE) in 1965 and by the United States of America Standards Institute in 1967 as a standard for all scientific and engineering literature.



1.2. Current and Voltage

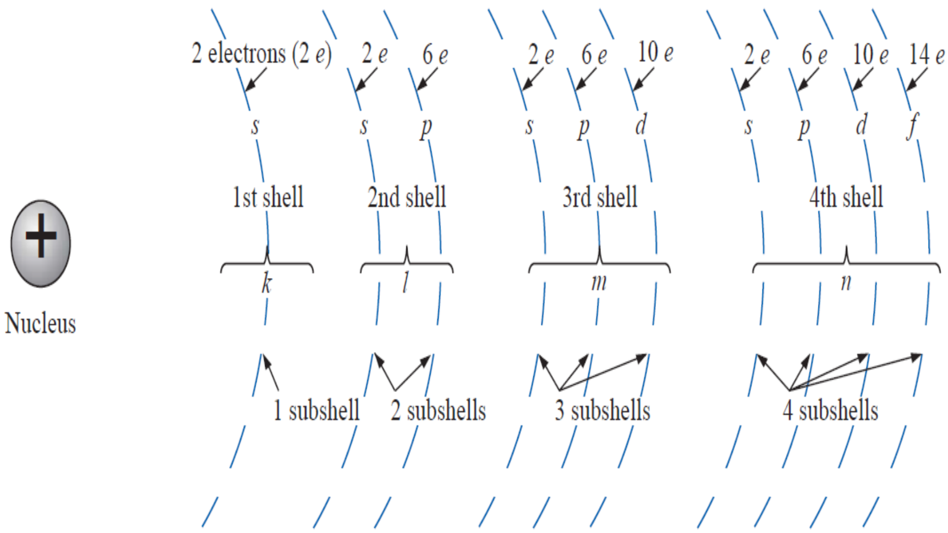
1.2.1 Introduction (JOHN DALTON)

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 that is equal in magnitude to the positive charge of the proton. In all other elements, the nucleus also contains neutrons, which are slightly heavier than protons and have no electrical charge. The helium atom, for example, has two neutrons in addition to two electrons and two protons. *In all*

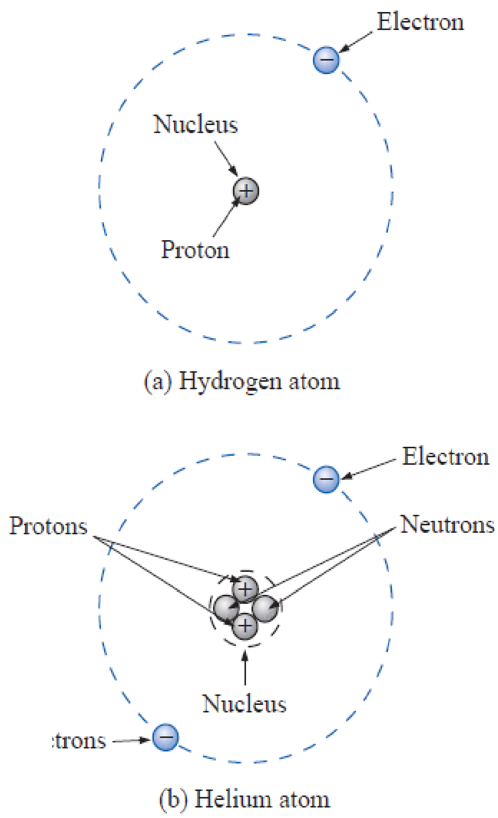
neutral atoms the number of electrons is equal to the number of protons. **The mass of the electron is 9.11×10^{-28} g, and that of the proton and neutron is 1.672×10^{-24} g.**

Different atoms will have various numbers of electrons in the concentric shells about the nucleus. The first shell, which is closest to the nucleus, can contain only two electrons. If an atom should have three electrons, the third must go to the next shell. The second shell can contain a maximum of eight electrons; the third, 18; and the fourth, 32; as determined by the equation $2n^2$, where n is the shell number. These shells are usually denoted by a number (n = 1, 2, 3, . . .) or letter (n = *k, l, m, . . .*).

Each shell is then broken down into subshells, where the first subshell can contain a maximum of two electrons; the second subshell, six electrons; the third, 10 electrons; and the fourth, 14. The subshells are usually denoted by the letters *s, p, d,* and *f,* in that order, outward from the nucleus.



Shells and subshells of the atomic structure.

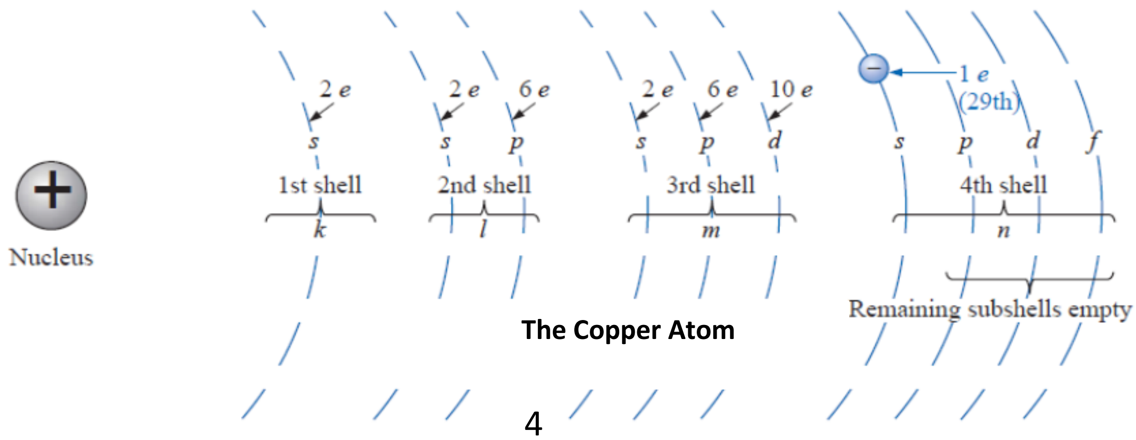


It has been determined by experimentation that unlike charges attract, and like charges repel. The force of attraction or repulsion between two charged bodies Q1 and Q2 can be determined by Coulomb's law:

$$F\ (\text{attraction or repulsion}) = \frac{kQ_1Q_2}{r^2} \qquad \text{(Newtons)}$$

Where F is in newton, $k=9\times10^{9}\ Nm^2/C$, $Q1$ and $Q2$ are the charges in coulombs, and r is the distance in meters between the two charges.

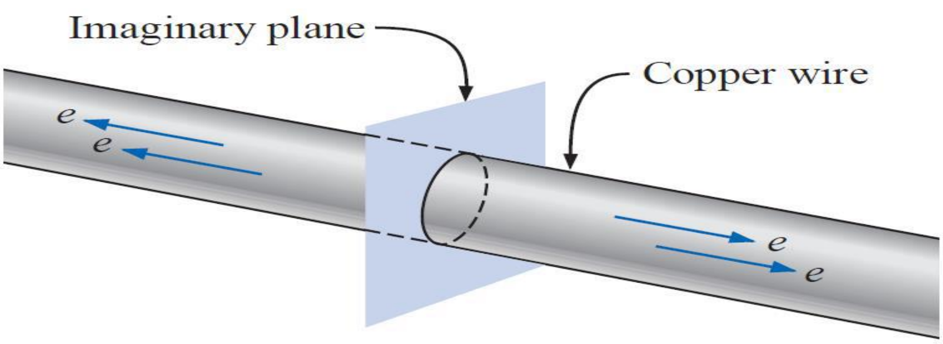
Copper is the most commonly used metal in the electrical/electronics industry. An examination of its atomic structure will help identify why it has such widespread applications. The copper atom has one more electron than needed to complete the first three shells. This incomplete outermost subshell, possessing only one electron, and the distance between this electron and the nucleus reveal that the twenty-ninth electron is loosely bound to the copper atom. If this twenty-ninth electron gains sufficient energy from the surrounding medium to leave its parent atom, it is called a free electron. In one cubic inch of copper at room temperature, there are approximately 1.4×10^{24} free electrons.



The Copper Atom

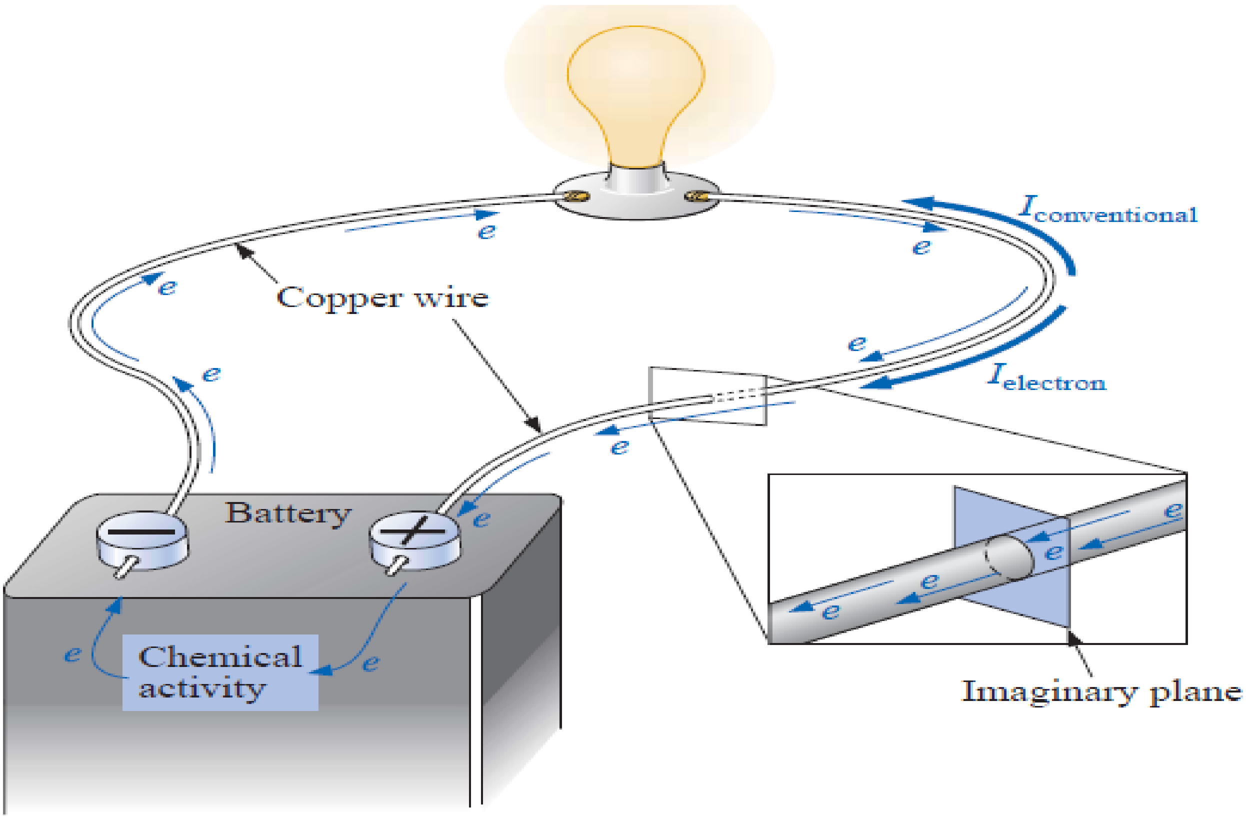
1.2.2. CURRENT

Consider a short length of copper wire cut with an imaginary perpendicular plane, producing the circular cross section. At room temperature with no external forces applied, there exists within the copper wire the random motion of free electrons created by the thermal energy that the electrons gain from the surrounding medium. When atoms lose their free electrons, they acquire a net positive charge and are referred to as positive ions. The free electrons are able to move within these positive ions and leave the general area of the parent atom, while the positive ions only oscillate in a mean fixed position. For this reason, *the free electron is the charge carrier in a copper wire or any other solid conductor of electricity*.



Random motion of electrons in a copper wire with no external "pressure" (voltage) applied.

Let us now connect copper wire between two battery terminals and a light bulb, to create the simplest of electric circuits. The battery, at the expense of chemical energy, places a net positive charge at one terminal and a net negative charge on the other. The instant the final connection is made, the free electrons (of negative charge) will drift toward the positive terminal, while the positive ions left



behind in the copper wire will simply oscillate in a mean fixed position. The negative terminal is a "supply" of electrons to be drawn from when the electrons of the copper wire drift toward the positive terminal.

The chemical activity of the battery will absorb the electrons at the positive terminal and will maintain a steady supply of electrons at the negative terminal. The flow of charge (electrons) through the bulb will heat up the filament of the bulb through friction to the point that it will glow red hot and emit the desired light. If 6.242×10^{18}*electrons* drift at uniform velocity through the imaginary circular cross section in 1 *second,* the flow of charge, or *current,* is said to be 1 ampere (A) in honor of André Marie Ampère.

In electric circuit, the charge is often carried by moving electrons in the wire. Therefore, electric current are follows of electric charge. The electric current is defined to be the rate at which charge flow across any cross sectional area. If an amount of charge ΔQ throughout a surface in a time interval Δt, then the average current I_{av} is given by:

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

The current in amperes can now be calculated using the following equation:

$$I = \frac{Q}{t}$$

$$I = \text{amperes (A)}$$
$$Q = \text{coulombs (C)}$$
$$t = \text{seconds (s)}$$

Example 1

The charge flowing through the imaginary surface is 0.16 C every 64 ms. Determine the current in amperes.

Example 2:

Determine the time required for 4×10^{16} electrons to pass through the imaginary surface if the current is 5 mA.(electron charge $1.602 \times 10^{-19}\, Colomb$) .

1.2.2.1. Current Density

It is about how much current is following across the given area and mathematically can be written as:

$$J = \frac{I}{A}$$

Example 3:

A copper wire of are 5mm² has a current of 5mA following through it. Calculate the current density?

1.2.3 Resistance

The flow of charge through any material encounters an opposing force similar in many respects to mechanical friction. This opposition, due to the collisions between electrons and between electrons and other atoms in the material, *which converts electrical energy into another form of energy such as heat,* is called the resistance of the material. The unit of measurement of resistance is the ohm, for which the symbol is Ω, the capital Greek letter omega.

The resistance of any material with a uniform cross-sectional area is determined by the following four factors:

1. ***Material***
2. ***Length***
3. ***Cross-sectional area***
4. ***Temperature***

At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

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

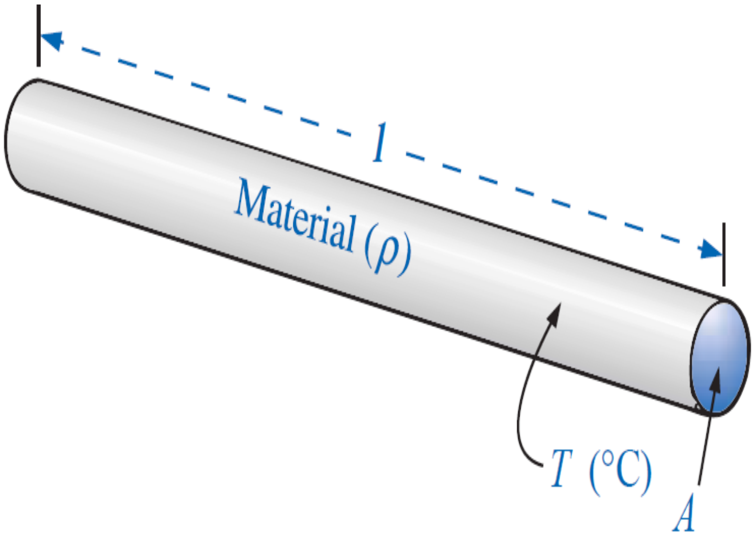
Where ρ (Greek letter rho) is a characteristic of the material called the resistivity, *l* is the length of the sample, and *A* is the cross-sectional area of the sample.

1.2.3.1 RESISTANCE: CIRCULAR WIRE

The resistivity ρ is also measured in ohms per mil-foot, or *ohm-meters* in the SI system of units. Some typical values of ρ are:

Resistivity (ρ) of various materials.

Material	ρ @ 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



For circular wires, the quantities $\rho, l, and\ A$ have the following units:

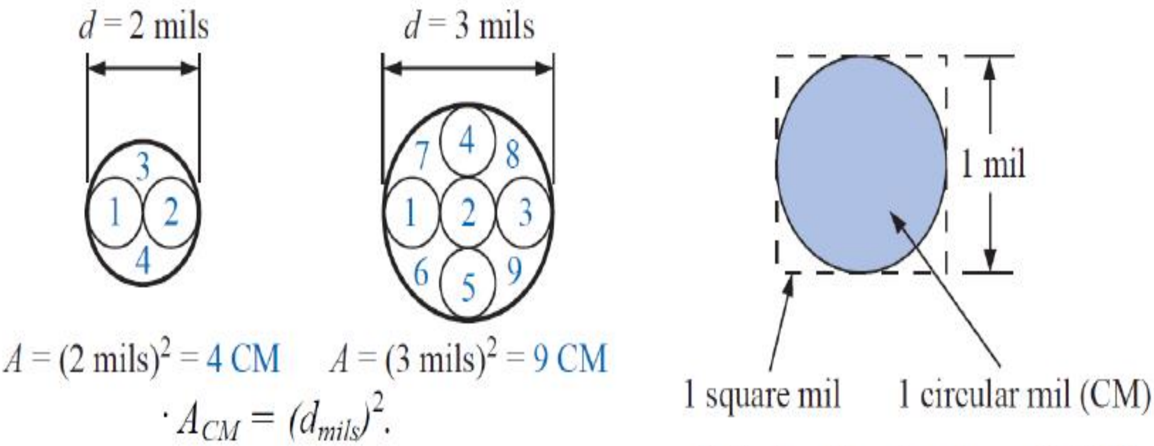
ρ: CM-ohms/ft at $T = 20°C$
l: feet
A: circular mils (CM)

Note that the area of the conductor is measured in circular mils (CM) and *not* in *square meters, inches,* and so on, as determined by the equation:

$$\text{Area (circle)} = \pi r^2 = \frac{\pi d^2}{4}$$

r = radius
d = diameter

***A wire with a diameter of 1 mil has an area of 1 circular mil (CM),* the area in circular mils is simply equal to the diameter in mils square; that is: $A_{CM} = (d_{mils})^2$**



Defining the circular mil (CM).

EXAMPLE 4

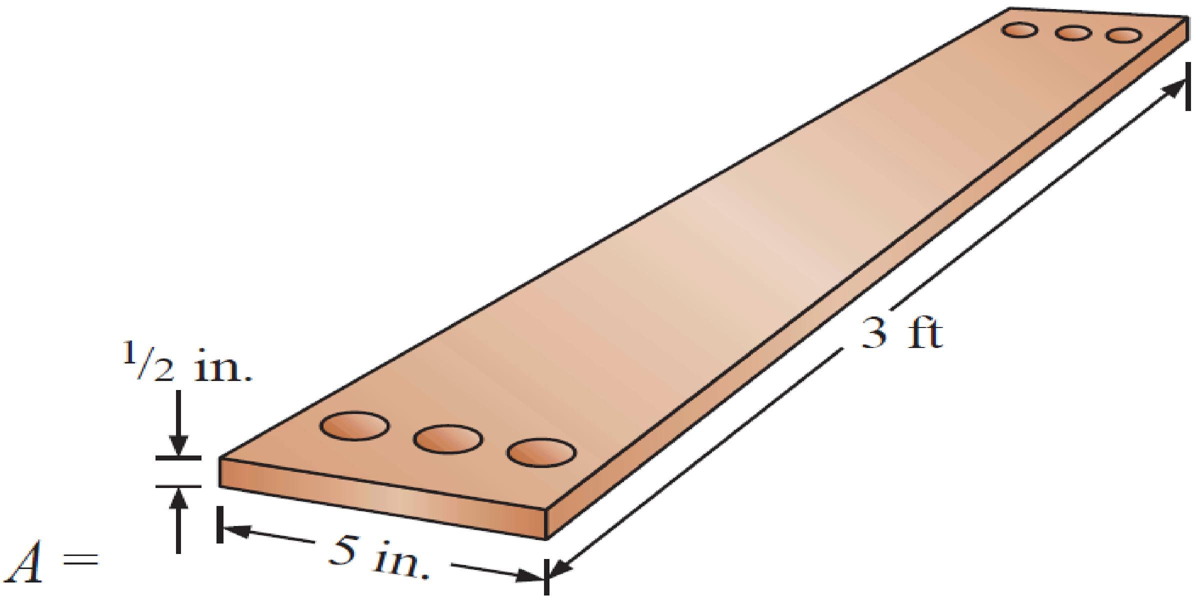
What is the resistance of a 100-ft length of copper wire with a diameter of 0.020 in. at 20°C?

EXAMPLE 5

An undetermined number of feet of wire have been used. Find the length of the remaining copper wire if it has a diameter of 1/16 in. and a resistance of 0.5 Ω.

EXAMPLE 6

What is the resistance of a copper bus-bar, as used in the power distribution panel of a high-rise office building, with the dimensions indicated in Fig. below?



1.2.3.2 WIRE TABLES

The wire table was designed primarily to standardize the size of wire produced by manufacturers throughout the United

States. 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. The American Wire Gage (AWG) sizes are given in Table below for solid round copper wire. A column indicating the maximum allowable current in amperes, as determined by the National Fire Protection Association, has also been included.

American Wire Gage (AWG) sizes.

	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	6,529.0	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	

EXAMPLE 8

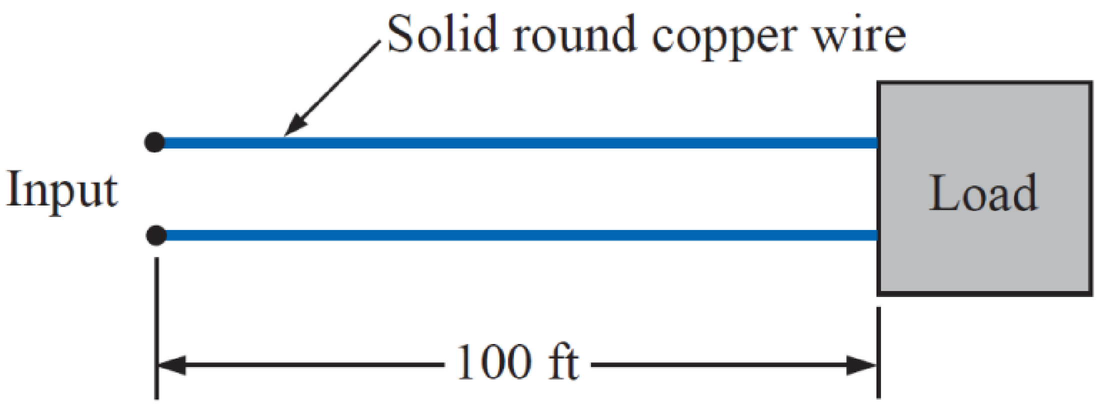
Find the resistance of 650 ft of #8 copper wire (*T* =20°C).

EXAMPLE 9

What is the diameter, in inches, of a #12 copper wire?

EXAMPLE 10

For the system of Fig. below, the total resistance of *each* power line cannot exceed 0.025 Ω, and the maximum current to be drawn by the load is 95 A. What gage wire should be used?



1.2.3.3 RESISTANCE: METRIC UNITS

The design of resistive elements for various areas of application, including thin-film resistors and integrated circuits, uses metric units for the quantities. In SI units, the resistivity would be measured in ohm-meters, the area in square meters, and the length in meters. However, the meter is generally too large a unit of measure for most applications, and so the centimeter is usually employed. The resulting dimensions are therefore

ρ:	ohm-centimeters
l:	centimeters
A:	square centimeters

Table below provides a list of values of r in ohm-centimeters.

Resistivity (ρ) of various materials in ohm-centimeters.

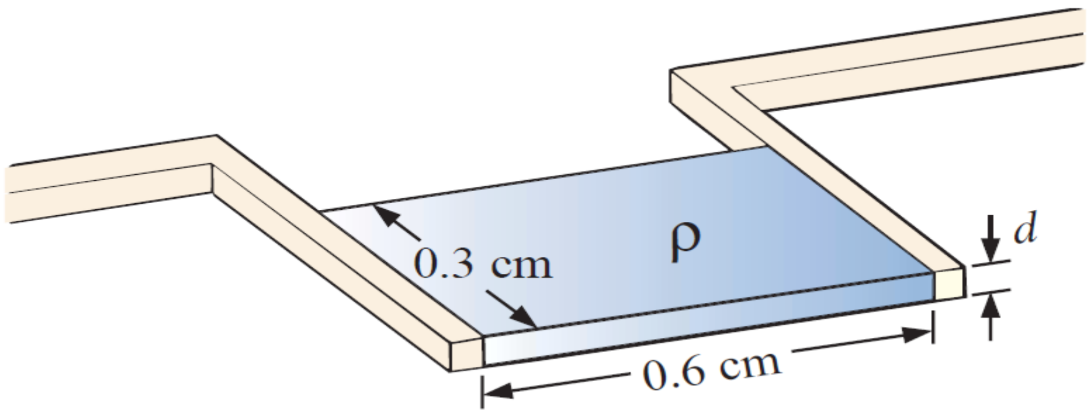
Silver	1.645×10^{-6}
Copper	$\mathbf{1.723 \times 10^{-6}}$
Gold	2.443×10^{-6}
Aluminum	2.825×10^{-6}
Tungsten	5.485×10^{-6}
Nickel	7.811×10^{-6}
Iron	12.299×10^{-6}
Tantalum	15.54×10^{-6}
Nichrome	99.72×10^{-6}
Tin oxide	250×10^{-6}
Carbon	3500×10^{-6}

EXAMPLE 11

Determine the resistance of 100 ft of #28 copper telephone wire if the diameter is 0.0126 in.

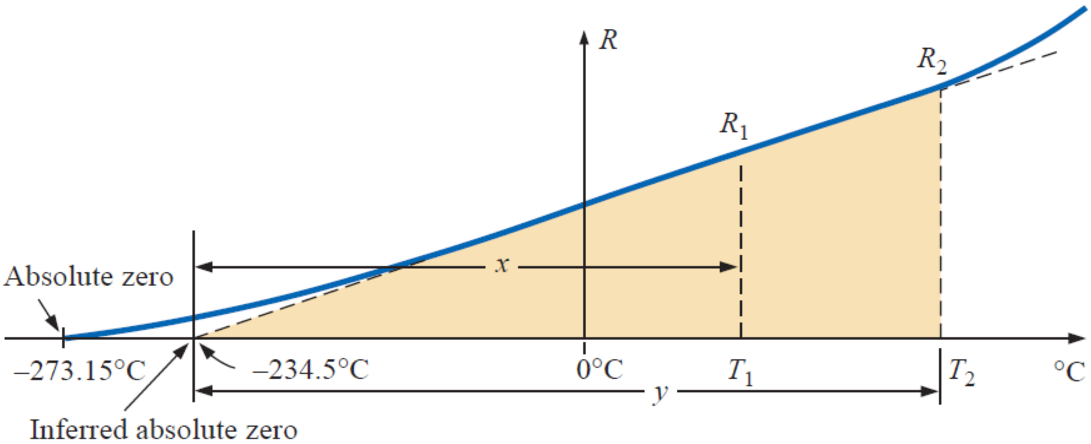
EXAMPLE 12

Determine the resistance of the thin-film resistor of Fig. below if the sheet resistance *Rs* (defined by *Rs* =r/*d*) is 100 Ω.



1.2.3.4. TEMPERATURE EFFECTS

Temperature has a significant effect on the resistance of conductors, semiconductors, and insulators.



Effect of temperature on the resistance of copper.

$$\frac{x}{R1} = \frac{y}{R2}$$

OR

$$\frac{234.5 + T1}{R1} = \frac{234.5 + T2}{R2}$$

EXAMPLE 13

If the resistance of a copper wire is 50 Ω at 20°C, what is its resistance at 100°C (boiling point of water)?

EXAMPLE 14

If the resistance of a copper wire at freezing (0°C) is 30 Ω, what is its resistance at -40°C?

EXAMPLE 15

If the resistance of aluminum wire at room temperature (20°C) is 100 mΩ (measured by a mille-ohmmeter), at what temperature will its resistance increase to 120 mΩ?

1.2.3.5 Temperature Coefficient of Resistance

There is a second popular equation for calculating the resistance of a conductor at different temperatures.

$$\alpha_{20} = \frac{1}{|T1| + 20}$$

as the temperature coefficient of resistance at a temperature of 20°C, and *R*20 as the resistance of the sample at 20°C, the resistance *R*1 at a temperature *T*1 is determined by:

$$R1 = R1[1 + \alpha_{20}(T1 - 20)$$

Temperature coefficient of resistance for various conductors at 20°C.

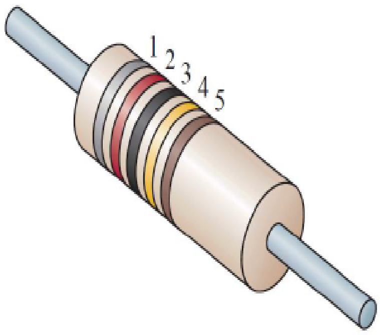
Material	Temperature Coefficient (α_{20})
Silver	0.0038
Copper	0.00393
Gold	0.0034
Aluminum	0.00391
Tungsten	0.005
Nickel	0.006
Iron	0.0055
Constantan	0.000008
Nichrome	0.00044

1.2.3.6. COLOR CODING AND STANDARD RESISTOR VALUE

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 fixed molded composition resistor, four or five color bands are printed on one end of the outer casing

Resistor color coding.

Bands 1–3*	Band 3	Band 4	Band 5
0 Black	0.1 Gold (multiplying factors)	5% Gold	1% Brown
1 Brown	0.01 Silver (multiplying factors)	10% Silver	0.1% Red
2 Red		20% No band	0.01% Orange
3 Orange			0.001% Yellow
4 Yellow			
5 Green			
6 Blue			
7 Violet			
8 Gray			
9 White			



EXAMPLE 16

Find the range in which a resistor having the following color bands must exist to satisfy the manufacturer's tolerance:

a. 1st band	**2nd band**	**3rd band**	**4th band**	**5th band**
Gray	**Red**	**Black**	**Gold**	**Brown**
8	**2**	**0**	**5%**	**1%**

b. 1st band	**2nd band**	**3rd band**	**4th band**	**5th band**
Orange	**White**	**Gold**	**Silver**	**No color**
3	**9**	**0.1**	**10%**	

1.2.4 VOLTAGE

The flow of charge is established by an external "pressure" derived from the energy that a mass has by virtue of its position: potential energy. Energy, by definition, is the capacity to do work. If a mass (m) is raised to some height (h) above a reference plane, it has a measure of potential energy expressed in joules (J) that is determined by

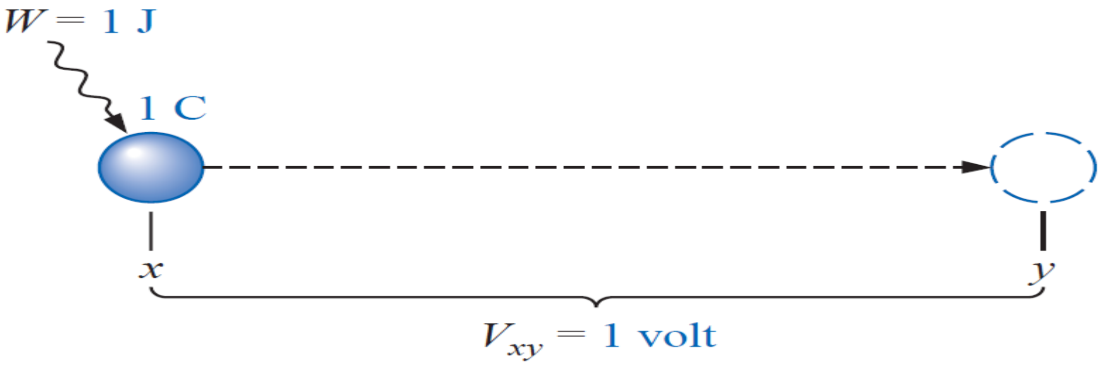
$$W = mgh\ Joules.(J)$$

Where *g* is the gravitational acceleration (9.754 m ⁄s^2). This mass now has the "potential" to do work such as crush an object placed on the reference plane.

In the battery, the internal chemical action will establish (through an expenditure of energy) an accumulation of negative charges (electrons) on one terminal (the negative terminal) and positive charges (positive ions) on the other (the positive terminal). A "positioning" of the charges has been established that will result in a potential difference between the terminals. If a conductor is connected between the terminals of the battery, the electrons at the negative terminal have sufficient potential energy to overcome collisions with other particles in the conductor and the repulsion from similar charges to reach the positive terminal to which they are attracted.

A potential difference of 1 volt (V) exists between two points if 1 joule (J) of energy is exchanged in moving 1 coulomb (C) of charge between the two points.

The unit of measurement volt was chosen to honor Alessandro Volta. Pictorially, if one joule of energy (1 J) is required to move the one coulomb (1 C) of charge of Fig. 2.10 from position *x* to position *y,* the potential difference or voltage between the two points is one volt (1 V).



Defining the unit of measurement for voltage.

a potential difference or voltage is always measured between two points in the system. Changing either point may change the potential difference between the two points under investigation.

In general, the potential difference between two points is determined by

$$V = \frac{W}{Q}$$

Example 17

Find the potential difference between two points in an electrical system if 60 J of energy are expended by a charge of 20 C between these two points.

Example 18

Determine the energy expended moving a charge of 50 mC through a potential difference of 6 V. Determine the energy expended moving a charge of 50 mC through a potential difference of 6 V.

Example 19

Find the voltage drop from the point a to point b, if 24J are required to move charge of 3C from point a to point b.

1.2.5 Power

Is an indication of how much work can be accomplished in a specific amount of time, that is a rate of doing work.

Power measure in watt (W), and work in Joule (J).

$$P = \frac{W}{t}$$

1 hours power hp =746 watt

$$P = \frac{W}{t} = \frac{QV}{t} = IV$$

Example 20

Find the power delivered to the d.c motor if the voltage applied is 120 v and the current equal to 5A.

1.2.6. Energy

Electric energy used or produced is the product of the electric power and the time

W (kilo watt hours) =P (kilo watt) x t (hour) (Joules)

Example 21

For the dial positions reading 5360, calculate the electricity bill if the previous reading was 4650 Kwh and the average coast is 7 € per kilo watt hour.

Example 22

What is the total coast of using the following loads at 7 € per kilo watt hour.

a- 1200 w toaster for 30 min

b- Six 50 w bulb for 4 h.

c- 400 w washing machine for 45 min

d- 4800 w electric clothes dryer for 20 min

1.2.7 Efficiency

Any electrical systems that convert energy from one form to another can be represented as

Input energy=output energy+ energy stored in the system or lost

$$\frac{W_{in}}{t} = \frac{W_{out}}{t} + \frac{W_{lost}}{t}$$

$$P_{in} = P_{out} + P_{lost}$$

$$Efficiency = \eta = \frac{output\ power}{input\ power} \times 100\%$$

Example 23

A 2 hp motor operates at an efficiency of 75%, what is the power input in watt? If the input current is 9.05 A what is the input voltage?

Fundamentals of Electrical Engineering.

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FIRST LEVEL/Second Semester/2019-2020

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