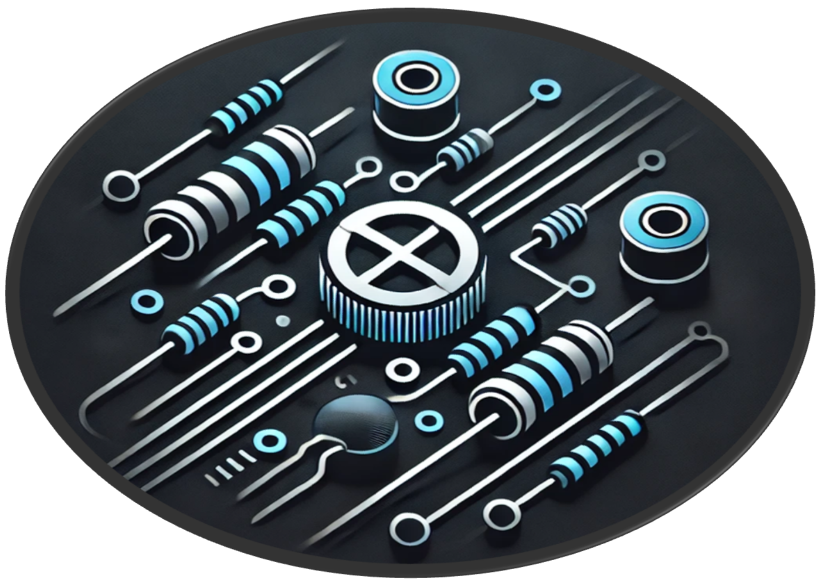
Ministry of Higher Education and Scientific Research
Al-Mustaqbal University

Computer Engineering Technologies Department



Lecturer: Zahraa Hazim

Electrical Engineering Fundamentals

Supplementary books:

1. **Fundamentals of Electric Circuits – Charles K. Alexander & Matthew N. O. Sadiku**
2. **Electrical Engineering: Principles and Applications – Allan R. Hambley**

Email: zahraa.hazim@uomus.edu.iq

FUNDAMENTALS OF DC CIRCUITS

CURRENT

Consider a short length of copper wire cut with an imaginary perpendicular plane, producing the circular cross section shown in Fig. 1.1. 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.

The free electron is the charge carrier in a copper wire or any other solid conductor of electricity.

An array of positive ions and free electrons is depicted in Fig. 1.2.

With no external forces applied, the net flow of charge in a conductor in any one direction is zero.

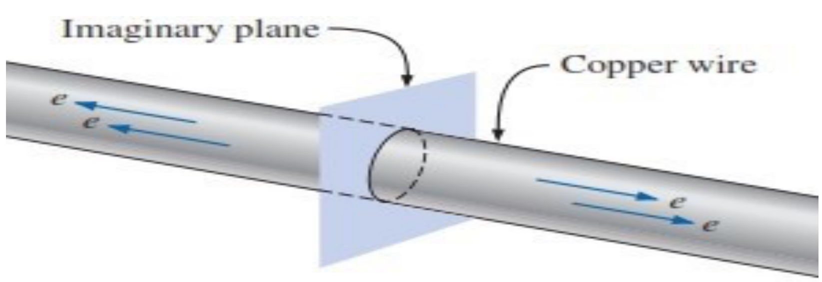


Fig.1.1

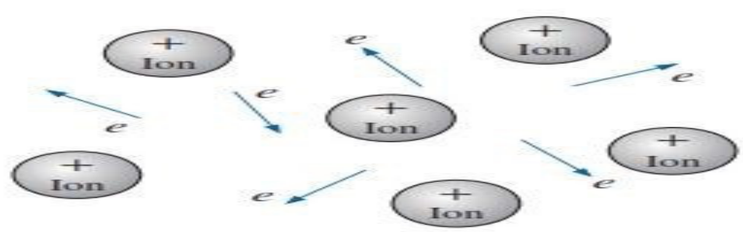


Fig.1.2

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Let us now connect copper wire between two battery terminals and a light bulb, as shown in Fig. 1.3, to create the simplest of electric circuits.

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 X 10^{18}** *electrons drift at uniform velocity through the imaginary* circular cross section of Fig. 1.3 in 1 *second,* the flow of charge, or *current, is said to be 1* ***Ampere (A) in honor of André Marie Ampère***. It is an enormous number of electrons passing through the surface in 1 second. a **Coulomb (C)** of charge was defined as the total charge associated with 6.242 X 1018 electrons. The charge associated with one electron can then be determined from Fig.1.3

$$\text{Charge/electron} = Q_e = \frac{1\ \text{C}}{6.242 \times 10^{18}} = 1.6 \times 10^{-19}\ \text{C}$$

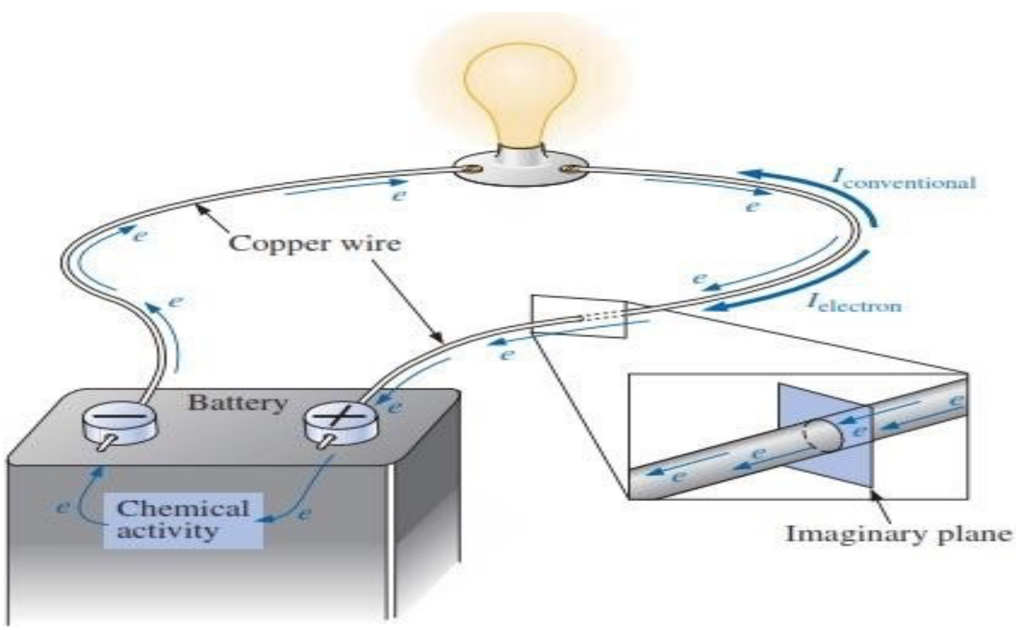

Fig.1.3

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

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

I = amperes (A)
Q = coulombs (C)
t = seconds (s)

$$Q = It \quad \text{(coulombs, C)}$$

$$t = \frac{Q}{I} \quad \text{(seconds, s)}$$

EXAMPLE 1.1 The charge flowing through the imaginary surface of Fig.1.3 is 0.16 C every 64 ms. Determine the current in amperes.

$$I = \frac{Q}{t} = \frac{0.16\text{ C}}{64 \times 10^{-3}\text{ s}} = \frac{160 \times 10^{-3}\text{ C}}{64 \times 10^{-3}\text{ s}} = \mathbf{2.50\ A}$$

EXAMPLE 1.2 Determine the time required for 4×10^{16} electrons to pass through the imaginary surface of Fig. 1.3 if the current is 5 mA.

$$4 \times 10^{16}\ \text{electrons}\left(\frac{1\text{ C}}{6.242 \times 10^{18}\ \text{electrons}}\right) = 0.641 \times 10^{-2}\text{ C}$$

$$= 0.00641\text{ C} = 6.41\text{ mC}$$

$$t = \frac{Q}{I} = \frac{6.41 \times 10^{-3}\text{ C}}{5 \times 10^{-3}\text{ A}} = \mathbf{1.282\ s}$$

VOLTAGE

The flow of charge described in the previous section 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*

$$W \text{ (potential energy)} = mgh \qquad \text{(joules, J)}$$

where ***g*** *is the gravitational acceleration (9.754 m/s2)*

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.

Pictorially, if one joule of energy (1J) is required to move the one coulomb (1C) of charge of Fig.1.4 from position *x to position y, the* potential difference or voltage between the two points is one volt (1V).

If the energy required to move the 1 C of charge increases to 12 J due to additional opposing forces, then the potential difference will increase to 12 V.

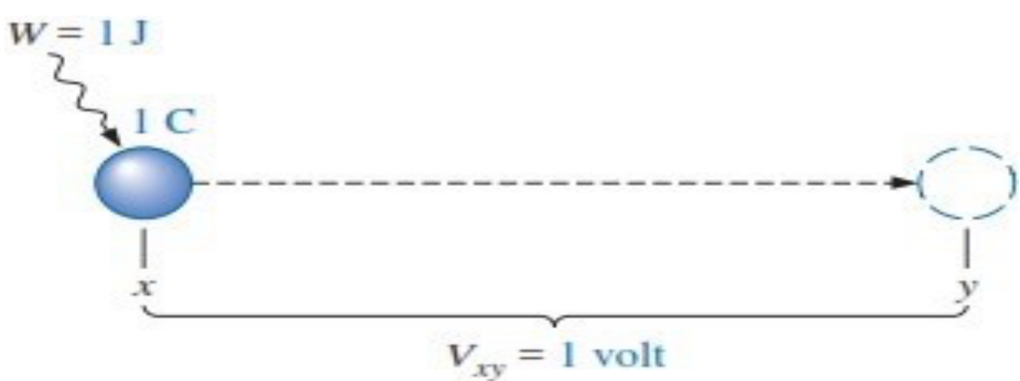

Fig.1.4

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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

$$V = \frac{W}{Q} \quad \text{(volts)}$$

$$W = QV \quad \text{(joules)} \qquad Q = \frac{W}{V} \quad \text{(coulombs)}$$

EXAMPLE 1.3 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.

$$V = \frac{W}{Q} = \frac{60\ \text{J}}{20\ \text{C}} = \mathbf{3\ V}$$

EXAMPLE 1.4 Determine the energy expended moving a charge of 50 μC through a potential difference of 6 V.

$$W = QV = (50 \times 10^{-6}\ \text{C})(6\ \text{V}) = 300 \times 10^{-6}\ \text{J} = \mathbf{300\ \mu J}$$

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To distinguish between sources of voltage (batteries and the like) and losses in potential across dissipative elements, the following notation will be used:

E for voltage sources (volts)
V for voltage drops (volts)

IMPORTANT DEFINITIONS

- ***Potential: The voltage at a point with respect to another point in the electrical system. Typically, the reference point is ground, which is at zero potential.***

- ***Potential difference: The algebraic difference in potential (or voltage) between two points of a network.***

- ***Voltage: When isolated, like potential, the voltage at a point with respect to some reference such as ground (0 V).***

- ***Voltage difference: The algebraic difference in voltage (or potential) between two points of the system. A voltage drop or rise is as the terminology would suggest.***

- ***Electromotive force (emf): The force that establishes the flow of charge (or current) in a system due to the application of a difference in potential. This term is not applied that often in today's literature but is associated primarily with sources of energy.***

CONDUCTORS AND INSULATORS

Conductors: ***are those materials that permit a generous flow of electrons with very little external force (voltage) applied.***
Insulators: ***are those materials that have very few free electrons and require a large, applied potential (voltage) to establish a measurable current level.***

Relative conductivity of various materials.

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

Breakdown strength of some common 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

SEMICONDUCTORS

Semiconductors ***are a specific group of elements that exhibit characteristics between those of insulators and conductors.***
Although *silicon (Si) is the most extensively employed material, germanium (Ge) and gallium arsenide (GaAs) are also used in many* important devices.

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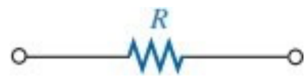
RESISTANCE



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

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

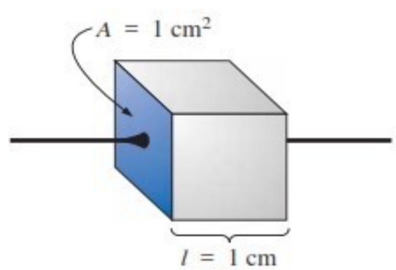
At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

$$R = \rho \frac{l}{A} \quad \text{(ohms, } \Omega\text{)}$$

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

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.
The units for ρ can be derived from

$$\rho = \frac{RA}{l} = \frac{\Omega \cdot \text{cm}^2}{\text{cm}} = \Omega \cdot \text{cm}$$



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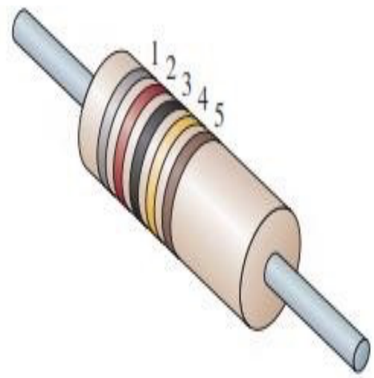
COLOR CODING AND STANDARD RESISTOR VALUES

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			

*With the exception that black is not a valid color for the first band.



Four or five color bands are printed on one end of the outer casing, as shown in Fig. Each color has the numerical value indicated in Table. The color bands are always read from the end that has the band closest to it, as shown.

1. The first and second bands represent the first and second digits, respectively.
2. The third band determines the power-of-ten multiplier for the first two digits (the number of zeros that follow the second digit) or a multiplying factor if gold or silver.
3. The fourth band is the manufacturer's tolerance, which is an indication of the precision by which the resistor was made. If the fourth band is omitted, the tolerance is assumed to be 20%.
4. The fifth band is a reliability factor, which gives the percentage of failure per 1000 hours of

CONDUCTANCE

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

$$G = \frac{1}{R} \qquad \text{(siemens, S)}$$

$$G = \frac{A}{\rho l} \qquad \text{(S)}$$

EXAMPLE 1.5 What is the relative increase or decrease in conductivity of a conductor if the area is reduced by 30% and the length is increased by 40%? The resistivity is fixed.

$$G_i = \frac{A_i}{\rho_i l_i}$$

with the subscript i for the initial value. Using the subscript n for new value:

$$G_n = \frac{A_n}{\rho_n l_n} = \frac{0.70A_i}{\rho_i(1.4l_i)} = \frac{0.70}{1.4}\frac{A_i}{\rho_i l_i} = \frac{0.70}{1.4}G_i$$

and $\qquad G_n = \mathbf{0.5G_i}$

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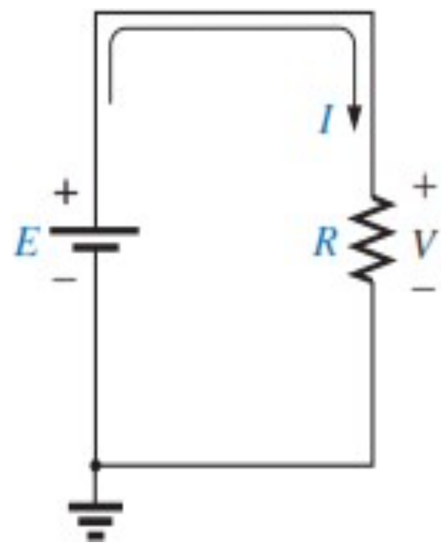
OHM'S LAW

$$\text{Current} = \frac{\text{potential difference}}{\text{resistance}}$$

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

$$E = IR \quad \text{(volts, V)}$$

$$R = \frac{E}{I} \quad \text{(ohms, }\Omega\text{)}$$



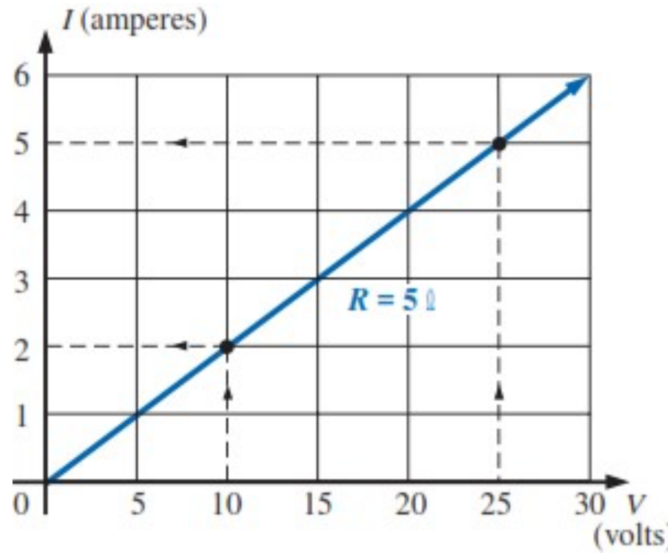
EXAMPLE 1.6 Calculate the resistance of a 60-W bulb if a current of 500 mA results from an applied voltage of 120 V.

$$R = \frac{E}{I} = \frac{120\ \text{V}}{500 \times 10^{-3}\ \text{A}} = \mathbf{240\ \Omega}$$

PLOTTING OHM'S LAW

If the resistance of a plot is unknown, it can be determined at any point on the plot since a straight line indicates a fixed resistance. At any point on the plot, find the resulting current and voltage, and simply substitute into the following equation:

$$R_{dc} = \frac{V}{I}$$

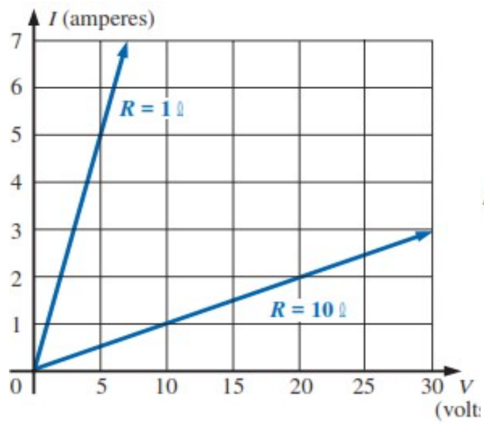


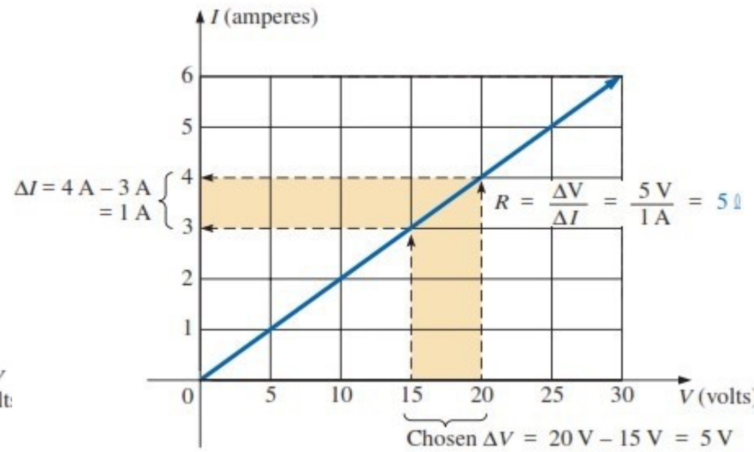
If we write Ohm's law in the following manner and relate it to the basic **straight-line equation**

we find that the slope is equal to 1 divided by the resistance value, as indicated by the following:

$$I = \frac{1}{R} \cdot E + 0$$
$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$
$$y = m \cdot x + b$$

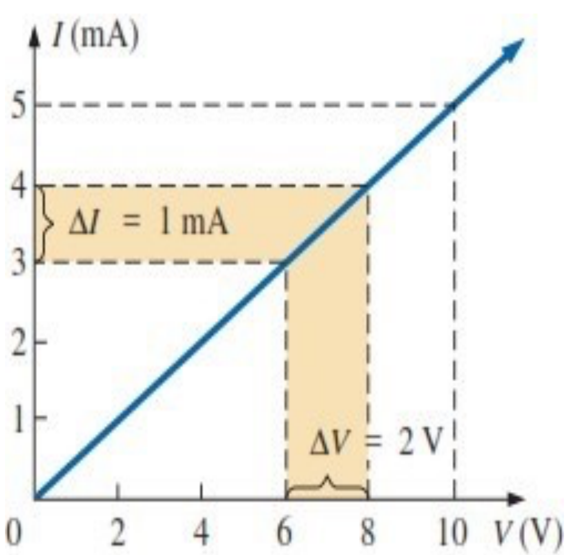
$$m = \text{slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta I}{\Delta V} = \frac{1}{R}$$





$$R = \frac{\Delta V}{\Delta I} \quad \text{(ohms)}$$

EXAMPLE 1.7 Determine the resistance associated with the curve shown.



At $V = 6$ V, $I = 3$ mA, and

$$R_{dc} = \frac{V}{I} = \frac{6\text{ V}}{3\text{ mA}} = \mathbf{2\ k\Omega}$$

For the interval between 6 V and 8 V,

$$R = \frac{\Delta V}{\Delta I} = \frac{2\text{ V}}{1\text{ mA}} = \mathbf{2\ k\Omega}$$

Before leaving investigate the subject, let us a first characteristics of y called Important semiconductor device **diode**

At $V = +1$ V,

$$R_{diode} = \frac{V}{I} = \frac{1\text{ V}}{50\text{ mA}} = \frac{1\text{ V}}{50 \times 10^{-3}\text{ A}}$$

$$= 20\ \Omega$$

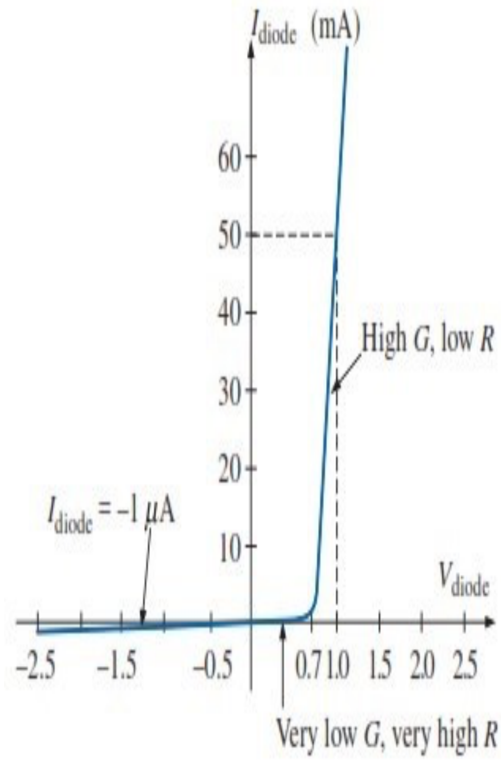
(a relatively low value for most applications)

At $V = -1$ V,

$$R_{diode} = \frac{V}{I} = \frac{1\text{ V}}{1\ \mu\text{A}}$$

$$= 1\text{ M}\Omega$$

(which is often represented by an open-circuit equivalent)



Email: zahraa.hazim@uomus.edu.iq

POWER

Power is an indication of how much work (the conversion of energy from one form to another) can be done in a specified amount of time, that is, a *rate of doing work.*

Since converted energy is measured in *joules (J) and time in seconds (s), power is measured* in joules/second (J/s). **The electrical unit of measurement for power is the watt (W),** defined by

$$1 \text{ watt (W)} = 1 \text{ joule/second (J/s)}$$

In equation form, power is determined by

$$P = \frac{W}{t} \qquad \text{(watts, W, or joules/second, J/s)}$$

James Watt introduced the **horsepower (hp)** as a measure of the average power of a strong dray horse over a full working day. It is approximately 50% more than can be expected from the average horse. The horsepower and watt are related in the following manner:

$$1 \text{ horsepower} \cong 746 \text{ watts}$$

The power delivered to, or absorbed by, an electrical device or system can be found in terms of the current and voltage

$$P = \frac{W}{t} = \frac{QV}{t} = V\frac{Q}{t}$$

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

$$\boxed{P = VI} \quad \text{(watts)}$$

By direct substitution of Ohm’s law, the equation for power can be obtained in two other forms:

$$P = VI = V\left(\frac{V}{R}\right)$$

and $$\boxed{P = \frac{V^2}{R}} \quad \text{(watts)}$$

or $$P = VI = (IR)I$$

and $$\boxed{P = I^2R} \quad \text{(watts)}$$

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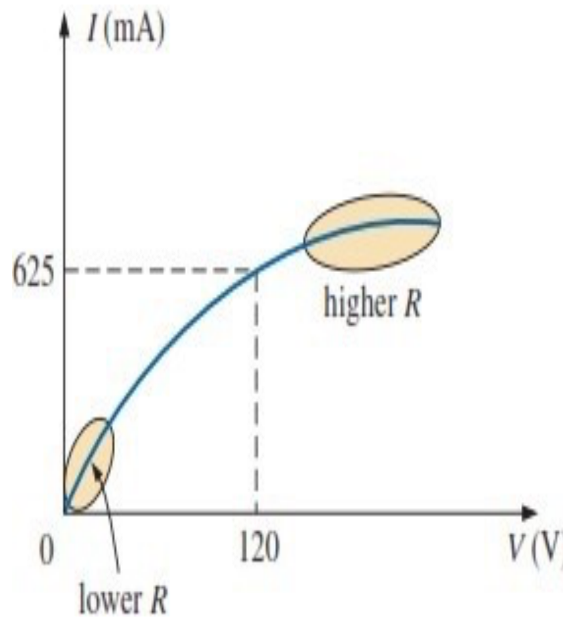
EXAMPLE 1.8 What is the power dissipated by a 5-Ω resistor if the current is 4 A?

$$P = I^2R = (4\ \text{A})^2(5\ \Omega) = \mathbf{80\ W}$$

EXAMPLE 1.9 The *I-V characteristics of a light bulb are provided*. Note the nonlinearity of the curve, indicating a wide range in resistance of the bulb with applied voltage. If the rated voltage is 120 V, find the wattage rating of the bulb. Also calculate the resistance of the bulb under rated conditions.



At 120 V,

$$I = 0.625\ \text{A}$$

and $$P = VI = (120\ \text{V})(0.625\ \text{A}) = \mathbf{75\ W}$$

At 120 V,

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.625\ \text{A}} = \mathbf{192\ \Omega}$$

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$$P = I^2R \Rightarrow \quad I^2 = \frac{P}{R} \qquad \boxed{I = \sqrt{\frac{P}{R}}} \qquad \text{(amperes)}$$

$$P = \frac{V^2}{R} \Rightarrow \quad V^2 = PR \qquad \boxed{V = \sqrt{PR}} \qquad \text{(volts)}$$

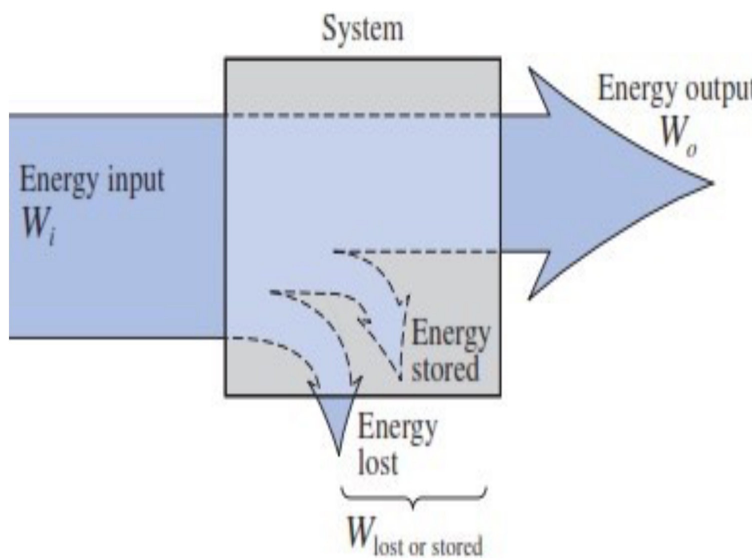
EXAMPLE 1.10 Determine the current through a 5-kΩ resistor when the power dissipated by the element is 20 mW.

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{20 \times 10^{-3}\ \text{W}}{5 \times 10^{3}\ \Omega}} = \sqrt{4 \times 10^{-6}} = 2 \times 10^{-3}\ \text{A}$$

$$= \mathbf{2\ mA}$$

EFFICIENCY

A flowchart for the energy levels associated with any system that converts energy from one form to another is shown. Take note of the fact that the output energy level must always be less than the applied energy due to losses and storage within the system. The best one can hope for is that *Wo* and *Wi* are relatively close in magnitude.



Conservation of energy requires that:
Energy input = energy output + energy lost or stored in the system
Dividing both sides of the relationship by *t gives*

$$\frac{W_{\text{in}}}{t} = \frac{W_{\text{out}}}{t} + \frac{W_{\text{lost or stored by the system}}}{t}$$

Since $P = W/t$, we have the following:

$$P_i = P_o + P_{\text{lost or stored}} \quad \text{(W)}$$

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The **efficiency (*η*)** of the system is then determined by the following equation:

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}}$$

$$\text{and} \qquad \eta = \frac{P_o}{P_i} \qquad \text{(decimal number)}$$

where η (lowercase Greek letter eta) is a decimal number. Expressed as a percentage,

$$\eta\% = \frac{P_o}{P_i} \times 100\% \quad \text{(percent)} \qquad \eta\% = \frac{W_o}{W_i} \times 100\% \quad \text{(percent)}$$

EXAMPLE 1.11 A 2-hp motor operates at an efficiency of 75%. What is the power input in watts? If the applied voltage is 220 V, what is the input current?

$$\eta\% = \frac{P_o}{P_i} \times 100\% \qquad \text{and} \qquad P_i = \frac{1492\text{ W}}{0.75} = \mathbf{1989.33\text{ W}}$$

$$0.75 = \frac{(2\text{ hp})(746\text{ W/hp})}{P_i} \qquad P_i = EI \quad \text{or} \quad I = \frac{P_i}{E} = \frac{1989.33\text{ W}}{220\text{ V}} = \mathbf{9.04\text{ A}}$$

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ENERGY

For power, which is the rate of doing work, to produce an energy conversion of any form, it must be *used over a period.* For example, a motor may have the horsepower to run a heavy load, but unless the motor is *used over a period, there will be no energy conversion.* In addition, the longer the motor is used to drive the load, the greater will be the energy expended. **The energy (*W) lost or gained by any system is therefore determined* by:**

$$W = Pt \qquad \text{(wattseconds, Ws, or joules)}$$

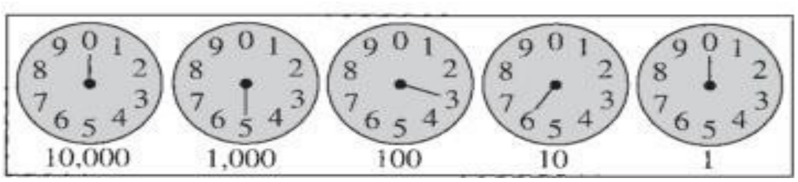
The watt second, however, is too small a quantity for most practical purposes, so the *watthour (Wh) and kilowatt-hour (kWh)* were defined, as follows:

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

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

Note that the energy in kilowatt-hours is simply the energy in watthours divided by 1000.To develop some sense for the kilowatt-hour energy level, consider that 1 kWh is the energy dissipated by a 100-W bulb in 10 h.

The **kilowatt-hour meter** is an instrument for measuring the energy supplied to the residential or commercial user of electricity.



EXAMPLE 1.12 For the dial positions of Fig. 4.22(a), calculate the electricity bill if the previous reading was 4650 kWh and the average cost is 9¢ per kilowatt-hour.

$$5360 \text{ kWh} - 4650 \text{ kWh} = 710 \text{ kWh used}$$

$$710 \cancel{\text{kWh}}\left(\frac{9¢}{\cancel{\text{kWh}}}\right) = \$63.90$$

Email: zahraa.hazim@uomus.edu.iq

EXAMPLE 1.13 How much energy (in kilowatt-hours) is required to light a 60-W bulb continuously for 1 year (365 days)?

$$W = \frac{Pt}{1000} = \frac{(60\ \text{W})(24\ \text{h/day})(365\ \text{days})}{1000} = \frac{525{,}600\ \text{Wh}}{1000}$$
$$= \mathbf{525.60\ kWh}$$

EXAMPLE 1.14 How long can a 205-W television set be on before using more than 4 kWh of energy?

$$W = \frac{Pt}{1000} \Rightarrow \quad t\ (\text{hours}) = \frac{(W)(1000)}{P}$$
$$= \frac{(4\ \text{kWh})(1000)}{205\ \text{W}} = \mathbf{19.51\ h}$$

EXAMPLE 1.15 What is the cost of using a 5-hp motor for 2 h if the rate is 9¢ per kilowatt-hour?

$$W\ (\text{kilowatthours}) = \frac{Pt}{1000} = \frac{(5\ \text{hp} \times 746\ \text{W/hp})(2\ \text{h})}{1000} = 7.46\ \text{kWh}$$
$$\text{Cost} = (7.46\ \text{kWh})(9¢/\text{kWh}) = \mathbf{67.14¢}$$

PROBLEMS

SECTION 2.4 Current

1. Find the current in amperes if 12 mC of charge pass through a wire in 2.8 s.
2. If a current of 40 A exists for 0.8 min, how many coulombs of charge have passed through the wire?
3. If the current in a conductor is constant at 2 mA, how much time is required for 6 mC to pass through the conductor?
4. Will a fuse rate at 1 A "blow" if 86 C pass through it in 1.2 min?
5. Charge is flowing through a conductor at the rate of 420 C/min. If 742 J of electrical energy are converted to heat in 30 s, what is the potential drop across the conductor?

SECTION 2.3 Voltage

6.What is the voltage between two points if 1.2J of energy are required to move 0.4 mC between the two points?
7.If the potential difference between two points is 60 V, how much energy is expended to bring 8 mC from one point to the other?
8. Find the charge *Q that requires 96 J of energy to be moved* through a potential difference of 16 V.

SECTION 4.2 Ohm's Law

9. How much resistance is required to limit the current to 1.5 mA if the potential drop across the resistor is 6 V?
10. If a clock has an internal resistance of 7.5 k, find the current through the clock if it is plugged into a 120 V outlet.
11. The input current to a transistor is 20 mA. If the applied (input) voltage is 24 mV, determine the input resistance of the transistor.

SECTION 4.3 Plotting Ohm's Law

12. a. Plot the curve of *I (vertical axis) versus V (horizontal axis)* for a 120 Ω resistor. Use a horizontal scale of 0 to 100 V and a vertical scale of 0 to 1 A.
b. Using the graph of part (a), find the current at a voltage of 20 V and 50 V.
13. Sketch the internal resistance characteristics of a device that has an internal resistance of 20 Ω from 0 to 10 V, an internal resistance of 4 Ω from 10 V to 15 V, and an internal resistance of 1 Ω for any voltage greater than 15 V. Use a horizontal scale that extends from 0 to 20 V and a vertical scale that permits plotting the current for all values of voltage from 0 to 20 V.

SECTION 4.4 Power

14. a. How many joules of energy does a 2 W nightlight dissipate in 8 h?
b. How many kilowatt-hours does it dissipate?
15. How long must a steady current of 1.4 A exist in a resistor that has 3 V across it to dissipate 12 J of energy?
16. What is the maximum permissible current in a 120 Ω,2 W resistor? What is the maximum voltage that can be applied across the resistor?
17. A calculator with an internal 3 V battery draws 0.4 mW when fully functional.

a. What is the current demand from the supply?
b. If the calculator is rated to operate 500 h on the same battery, what is the ampere-hour rating of the battery?

Email: zahraa.hazim@uomus.edu.iq

SECTION 4.5 Energy

18. A 10 Ω resistor is connected across a 12 V battery.
a. How many joules of energy will it dissipate in 1 min?
b. If the resistor is left connected for 2 min instead of 1 min, will the energy have used increase? Will the power dissipation level increase?
19. How much energy in kilowatt-hours is required to keep a 230 W oil-burner motor running 12 h a week for 5 months? (Use 4 $_{1/3}$ weeks = 1 month.)
20. How long can a 1500 W heater be ON before using more than 12 kWh of energy?
21. A 60 W bulb is on for one hour. Find the energy converted in

a. watthours
b. watt seconds
c. joules
d. kilowatt-hours

SECTION 4.6 Efficiency

22. What is the efficiency of a motor that has an output of 0.5 hp with an input of 395 W?
23. What is the efficiency of a dryer motor that delivers 1 hp when the input current and voltage are 4 A and 220 V, respectively?
24. A motor is rated to deliver 2 hp.
a. If it runs on 110 V and is 90% efficient, how many watts does it draw from the power line? b. What is the input current?
c. What is the input current if the motor is only 70% efficient?
25. If two systems in cascade each have an efficiency of 80% and the input energy is 60 J, what is the output energy?
26. If the total input and output power of two systems in cascade are 400 W and 128 W, respectively, what is the efficiency of each system if one has twice the efficiency of the other?

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