**1.1 Introduction**

The study of an electrical engineering involves the analysis of the energy transfer from one form to another or from one point to another. So before beginning the actual study of an electrical engineering, it is necessary to discuss the fundamental ideas about the basic elements of an electrical engineering like electromotive force, current, resistance etc. The electricity is related with number of other types of systems like mechanical, thermal etc. To analyze such transfer, it is necessary to revise the **S.I.** units of measurement of different quantities like work, power, energy etc. in various systems.

**1.2 Concept of Charge**

Key Point: *Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).*

The following table (1.1) shows the different particles and charge possessed by them:

|  |  |  |
| --- | --- | --- |
| **Particle** | **Charge possessed in Coulomb** | **Nature** |
| **Neutron** | **0** | **Neutral** |
| **Proton** | **1.602×10-19** | **Positive** |
| **Electron** | **1.602×10-19** | **Negative** |

**1.2.1 Unit of Charge**

As seen from the **Table 1.2** that the charge possessed by the electron is very very small hence it is not convenient to take it as the unit of charge. The unit of the measurement of the charge is Coulomb, so one coulomb charge is defined as:

1 coulomb= charge on 6.24×1018 electrons

The charge associated with one electron can then be determined from

**1.3 Relation between Charge and Current**

The current is flow of electrons. Thus current can be measured by measuring how many electrons are passing through material per second. This can be expressed in terms of the charge carried by those electrons in the material per second.

Key Point: *Electric current is the time rate of change of charge, measured in amperes (A).*

Mathematically we can write the relation between the charge (**Q**) and the electric current (**I**) as,

(1.1)

Where current is measured in amperes (A), and

1 ampere = 1 coulomb/second

The charge transferred between time **t0** and **t** is obtained by integrating both sides of **Eq. (1.1)**. We obtain

(1.2)

**Ampere** (1.3)

Where **I** = average current flowing, **Q** = total charge transferred

**t** = time required for transfer of charge.

**Definition of 1 Ampere:** A current of 1 Ampere is said to be flowing in the conductor when a charge of one coulomb is passing any given point on it in one second.

1 Ampere current = Flow of 6.24× 1018 electrons per second

**Example 1.1:** Determine the time required for 4×1016 electrons to pass through the imaginary surface if the current is 5 mA.

**Solution:** Determine **Q**

Calculate **t**

**1.4 Resistance**

When the electrons begin flow in the metal. The ions get formed which are charged particles as discussed earlier. Now free electrons are moving in specific direction when connected to external source of **e.m.f.** (electromotive force), so such ions always become obstruction for the flowing electrons. Therefore, there is collision between ions and free flowing electrons. This not only reduces the speed of electrons but also produces the heat. The effect of this is the reduction of flow of current. Thus the material opposes the flow of current.

**Key Point**: ***This property of an electric current circuit tending to prevent the flow of current and at the same time causes electrical energy to be converted to heat is called resistance.***

The resistance is denoted by the symbol '**R**' and is measured in ohm symbolically represented as Ω. We can define unit ohm as below.

Key Point: ***1 Ohm: Is the resistance of a circuit, when a current of 1 Ampere generates the heat at the rate of one joule per second.***

**1.4.1 Factors Affecting the Resistance**

**1. Length of the material:** The Length is denoted by '***l***'.

**2. Cross-section area:** The cross sectional area is denoted by ' **a**'.

**3. The type and nature of the material:**

**4. Temperature:** The temperature of the material affects the value of the resistance.

For a certain material at a certain temperature we can write a mathematical expression as,

(1.4)

Where ***l***= length in meters, **a**= cross-sectional area in square meters

**ρ**= resistivity in ohms-meters, **R**= resistance in ohms

**1.5 Resistivity and Conductivity**

The resistivity or specific resistance of a material depends on nature of material and denoted by **ρ** (rho). From the **eq. (1.4)** of resistance it can be expressed as,

(1.5)

**Definition:** The resistance of the material having unit length and unit cross-sectional area is known as its specific resistance or resistivity.

**1.5.1 Conductance (G)**

The conductance of any material is reciprocal of its resistance and denoted as **G**. It is the indication of ease with which current can flow through the material. It is measured in **Siemens**.

(1.6)

**1.5.2 Conductivity**

The quantity (**1/ρ**) is called conductivity denoted as **σ** (**sigma**). Thus the conductivity is the reciprocal of resistivity. It is measured in **Siemens/m**.

**Key Point**: ***A material having highest value of conductivity is the best conductor while with poorest value of conductivity is the best insulator.***

**Example 1.2:** The resistance of copper wire 25 m long is found to be 50 **Ω**. If its diameter is 1**mm**, calculate the resistivity of copper

**Solution:** ***l***= 25 m*,*  **d** = l mm, **R** =50Ω

**a** =π/4(d2) = π/4(12) = 0.7853 mm2

= 1.57×10-6 Ω-m = 1.57 µΩ-m

**Example 1.3:** A silver wire has resistance of 2.5 **Ω**. What will be the resistance of a manganin wire having a diameter, half of the silver wire and length one third? The specific resistivity of manganin is 30 times that of silver.

**Solution: Rs** = silver resistance= 2.5 Ω, **dm**= manganin diameter = **ds**/2

***l*m**= manganin length=***l*s**/3, **ρm**= manganin specific resistance = 30 **ρs**

Now **as** =π/4(**ds**2) = area of cross section for silver

Resistance of manganin

**1.6 Effect of Temperature on Resistance**

 The resistance of the material is varied as temperature of a material change. For example, Atomic structure theory says that under normal temperature when the metal is subjected to potential difference, ions i.e. unmovable charged particles get formed inside the metal. The electrons which are moving randomly get aligned in a particular direction as shown in the **Figure 1.1**. If temperature increases, the ions gain energy and start oscillating about their mean position and cause collision and obstruction to the flowing electrons. Due to collision and obstruction due to higher amplitude of oscillations of ions, the resistance of material increases as temperature increases. However, this is not true for all materials. In some cases the resistance decreases as temperature increase.

**Figure 1.1 Vibrating ions in conductor.**

**1.6.1 Effect of Temperature on Metals**

The resistance of all the pure metals like copper, iron, tungsten etc. increases linearly with temperature. This is shown in the **Figure 1.2**.

**For good conductors, an increase in temperature will result in an increase in the resistance level. Consequently, conductors have a positive temperature coefficient.**

**Figure 1.2 effect of temperature on metals.**

**1.6.2 Effect of Temperature on Carbon and Insulator**

The effect of temperature on carbon and insulators is exactly opposite to that of pure metals. Resistance of carbon and insulators decreases as the temperature increase. The result is a negative temperature coefficient.

**1.6.3 Effect of Temperature on Alloys**

The resistance of alloys increases as the temperature increase but rate of increase is not significant. In fact, some of alloys show almost no change in resistance for considerable change in the temperature like Manganin (alloy of copper, manganese and nickel), Eureka (alloy of copper and nickel) etc. Due to this property, alloys are used to manufacture the resistance boxes. **Figure 1.3** shows the effect of temperature on metals, insulating materials and alloys.

**Figure 1.3 effect of temperature on resistance.**

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**1.6.4 Effect of Temperature on Semiconductors**

The materials having conductivity between that of metals and insulators are called semiconductors such as silicon, germanium etc. At absolute zero temperature, the semiconductors behave as perfect insulators.

For semiconductor materials, an increase in temperature will result in a decrease in the resistance level. Consequently, semiconductors have negative temperature coefficients.

**Figure 1.4 Effect of temperature on semiconductor.**

The thermistor and photoconductive cells are excellent examples of semiconductor devices with negative temperature coefficients.

**1.7 Mechanical Units**

The various mechanical units are,

**1. Mass:** It is the matter possessed by the body. It is measured in kg and denoted as **m**.

**2. Velocity:** It is the distance travelled per unit time, measured in m/ s and denoted as ***v***.

**3. Acceleration:** It is the rate of change of velocity measured in m/s2 and denoted as **a.**

**4. Force:** It is the push or pulls which changes or tends to change the state of rest or uniform motion of body, measured in Newton (**N**). One Newton is the force required to give an acceleration of l m/ s2 to a mass of 1 kg.

**F= m× a N** (1.12)

**5.** **Weight:** The gravitational force exerted by the earth on a body is called its weight, measured in Newton.

**Weight=m× g where g= gravitational acceleration = 9.81 m/s2** (1.13)

**6. Torque:** It is the product of a force and a perpendicular distance from the line or action of force to the axis of rotation. It is measured in N-m.

**T = F × r Where r =radial distance of rotation** (1.14)

**7. Work:** The work is said to be done when force acting on a body causes it to move. If a body moves through distance **d** under the force **F**; then

**W = F × d the work is measured in Joules.** (1.15)

**8. Energy:** It is the capacity to do the work. The work is done always at the cost of energy. The unit of energy is also Joules. The two forms of energy are

**i) Kinetic energy:** which is the energy possessed by a body due to its motion. If body of mass **m** is moving with velocity ***v*** then the kinetic energy is,

**K.E. = 1/2 (m *v*2) J**  (1.16)

**ii) Potential energy:** which is the energy possessed by a body due to its position. When a body of mass **m** is lifted vertically through height of **h** then the potential energy is

**P.E. = m×g×h = W× h J where W =weight** (1.17)

**9. Power:** The rate of doing work is power measured in **J/sec** i.e. **watts**

**P = work done/ time W** (1.18)

And  **1 W = 1 J/sec**

For American automobiles, engine power is rated in a unit called "**horsepower**," then

**1 Horsepower = 745.7 Watts**

**Energy expended = Power× time =work done**

**1.7.1 Relation between Torque and Power**

Consider a pulley of radius R and F is the force applied as shown in the **Figure 1.6**.

**T = F × R N-m**



**Figure 1.6**

Let speed of pulley is **N** revolution per minute. Now work done in one revolution is force into distance travelled in one revolution. **d = distance travelled in 1 revolution = 2πR**

**W = work done in 1 revolution = F × d = 2π R F** **J**

The time required for a revolution can be obtained from speed **N** r.p.m.

**t = time for a revolution = 60/N sec**

**P= T \*ω**  (1.19)

Where **T = F x R torque in N-m**

**ω= (2πN) / 60** angular velocity in rad/sec

The relation **P = T ω** is very important in analyzing various mechanical system,

**1.8 Electrical Units**

The various electrical units are

**1. Electrical work:** In an electric circuit, movement of electrons i.e. transfers of charges is an electric current. The electrical work is done when there is a transfer of charge. The unit of such work is Joule. So if V is potential difference in volts and Q is charge in coulombs then we can write,

Electrical work = **W =V × Q J** But **I= Q/t**,

**W =V.I.t J** where **t = time in second** (1.20)

**2. Electrical power:** The rate at which electrical work is done in an electric circuit is called an electrical power.

Electrical power = **P = electrical work / time = W / t = V.I.t / t**

**P=V.I J/sec i.e. watts** (1.21)

Thus power consumed in an electric circuit is 1 watt if the potential difference of 1 volt applied across the circuit causes 1 ampere current to flow through it.

**3. Electrical energy:** An electrical energy is the total amount of electrical work done in an electric circuit.

Electrical energy = **E = Power × Time = V.I.t joules** (1.22)

The unit of energy is joule or watt-sec. As watt-sec unit is very small, the electrical energy is measured in bigger units as watt-hour (**Wh**) and kilo watt-hour (**kWh**). When a power of 1 kW is utilized for 1 hour, the energy consumed is said to be **1 kWh**.

**1.8.1Efficiency**

The efficiency can be defined the ratio of energy output to energy input. It can be also expressed as ratio of power output to power input. Its value is always less than 1. Higher its value, more efficient is the system of equipment. Generally, it is expressed in percentage and its symbol is **η**.

% **η** = Energy output/ Energy input ×100

= Power output/ power input × 100

(1.26)