THERMAL, CHEMICAL AND MAGNETIC EFFECTS OF CURRENT

Ion

An atom, a molecule or a radical having charge is called as ion. If it has positive charge, it is called positive ion or cation and if it has negative charge, it is called negative ion or anion.

Electrolysis : The process of decomposition of a solution into ions on passing a current through it, is called electrolysis.

Electrolyte : The solution which allows passage of current through it and dissociates itself into ions, is called as electrolyte.

Faraday's laws of electrolysis :

First law : The mass of a substance deposited or liberated on an electrode during electrolysis is directly proportional to the total charge passed through the electrolyte, i.e.,

$$m \propto q$$

where m is the mass of the substance liberated or deposited when charge q is passed through the electrolyte.

or $$m = zq$$

where z = constant of proportionality, called as electrochemical equivalent (e.c.e.) of the substance.

Second law : When same quantity of electricity is allowed to pass through several electrolytes, the masses of the substances liberated or deposited at the electrodes are directly proportional to their chemical equivalents. i.e.,

$$\frac{m_1}{m_2} = \frac{E_1}{E_2}$$

Electro-chemical equivalent : Electro-chemical equivalent (e.c.e.) of a substance is defined as the mass of that substance liberated or deposited on an electrode, when one coulomb of charge is passed through the electrolyte. Its SI unit is gc^{-1}.

Faraday constant : It is the amount of charge required to liberate on gram equivalent of the substance. It is represented by F.

1 Faraday (F) = 96500 C mol^{-1}.

Thermocouple : It is an arrangement of two wires of dissimilar metals joined at their ends so as to form two junctions of a circuit.

Watt : The electric power of a circuit is said to be one watt when one ampere current flows through it on application of a potential difference of one volt across it.

$$1000 \text{ watt (W)} = 1 \text{ kilowatt (kW)}$$

Kilowatt hour : 1 kilowatt hour is the energy consumed when an electrical appliance of power 1 kilowatt is used for one hour.

Electric power : Rate of doing work in maintaining an electric current in the circuit is called as the electric power of the circuit. Hence,

$$\text{electric power (P)} = \frac{W}{t} = \frac{VIt}{t} = VI.$$

The S.I. unit of electric power is watt (W). Hence,

$$1 \text{ W} = 1 \text{ V} \times 1 \text{ A} = 1 \text{ Js}^{-1}$$

$$P = VI = I^2R = \frac{V^2}{R}$$

Electric energy : Electric energy consumed in a circuit is the total amount of work done in maintaining a current in it for a given time. Hence, Electric energy

$$W = JH = I^2RT$$
$$= VIt$$
$$= \frac{V^2t}{R}$$

Its S I unit is joule (J) and commercial unit is kilowatt hour (kWh).

Joule's law of heating : According to Joule's law of heating, the amount of heat (H) produced in a conductor due to flow of current is

(i) directly proportional to the square of the current (I) flowing through the conductor, i.e., $H \propto I^2$

(ii) directly proportional to the resistance (R) of the conductor i.e., $H \propto R$.

(iii) directly proportional to the time (t) for which current is passed through the conductor, i.e., $H \propto t$.

After combining the three, we get

$$H \propto I^2 Rt$$

or
$$H = \frac{I^2Rt}{J} \text{ cal}$$

where J is a constant, called as Joule's mechanical equivalent of heat. Its value is 4.18 J cal^{-1}.

Thermo-electric power (or Seebeck coefficient) : It is defined as the rate of change of thermo-e.m.f. with the temperature of the hot junction. It is also called as Seebeck coefficient and is denoted by S.

Peltier effect : According to Peltier effect, heat is either evolved or absorbed at a junction of two dissimilar metals, when an electric current is passed through it.

Peltier coefficient : It is defined as the amount of heat energy evolved or absorbed per second at a junction of two dissimilar metal, when unit electric current is passed through it. It is denoted by π.

Thomson effect : According to Thomson effect, an e.m.f. is developed between different parts of the some metal (or wire) when they are kept at different temperatures.

Thomson coefficient : It is defined as the amount of heat energy evolved or absorbed per second between two points of a conductor maintained at unit temperature difference, when unit electric current is passed through it. It is denoted by σ.

Relation between S, π and σ :

$$S = \frac{dE}{dT}$$

$$\pi = T\frac{dE}{dT}$$

$$\text{or } \frac{\pi}{T} = \frac{dE}{dT} = S$$

$$\sigma = -T\frac{d^2E}{dT^2}$$

$$= -T\frac{d}{dT}\left(\frac{dE}{dT}\right)$$

$$= -T\frac{dS}{dT}$$

where, $\frac{dE}{dT}$ = Rate of change of thermo-e.m.f. with temperature

S = Seebeck coefficient

π = Peltier coefficient

σ = Thomson coefficient

Galvanometer : It is an instrument used for detection of small currents in electrical circuits. It is connected in series in the circuit.

Ammeter : It is an instrument used for measurement of currents in electrical circuits. It has low resistance and is always connected in series in the circuit.

Voltmeter : It is an instrument used for measurement of potential differences across various parts of electrical circuits. It has high resistance and is always connected in parallel to the part across which potential difference is to be measured.

Shunt : It is low resistance which is usually connected in parallel with the coil of a galvanometer to convert it into an ammeter. Its resistance S can be calculated by using the relation,

$$S = \frac{I_g}{I - I_g} G$$

where, I = total current flowing through the ammeter

I_g = current flowing through the coil of the galvanometer for full scale deflection.

G = resistance of the coil of the galvanometer.

Multiplier : It is a high resistance which is usually connected in series with the coil of a galvanometer to convert it into a voltmeter. Its resistance R can be calculated by using the relation,

$$R = \frac{V}{I_g} - G$$

where, V = potential difference to be measured by the voltmeter.

I_g = current flowing through the coil of the galvanometer for full scale deflection.

G = resistance of the coil of the galvanometer.

Cyclotron frequency : The cyclotron frequency ν is given by,

$$\nu = \frac{1}{T} = \frac{Bq}{2\pi m}$$

where, T = time period of alternating electric field.

B = strength of the magnetic field.

q = charge of the positive ion.

m = mass of the positive ion.

Hall effect : The phenomenon of production of transverse e.m.f. in a current carrying metallic strip on applying a magnetic field in a direction perpendicular to the direction of electric current, is known as Hall effect. Hall voltage is given by the relation,

$$V_H = \frac{BI}{neb}$$

where, B = strength of the magnetic field.
I = current flowing through the metallic strip.
n = number of current carriers per unit volume of the strip.
e = charge on a current carrier.
b = thickness of the strip.

Current sensitivity : It is defined as the deflection produced in the galvanometer when unit current is passed through its coil.

It is given by

$$I_S = \frac{nBA}{C}$$

where, n = number of turns in the coil of the galvanometer.
B = magnetic field around the coil.
A = area of the coil.
C = restoring torque per unit radian twist.

Voltage sensitivity : It is defined as the deflection produced in the galvanometer when unit voltage is applied across its coil.

It is given by,

$$V_S = \frac{nBA}{CR}$$

where, R = resistance of the coil.

Fleming's left hand rule : According to this rule, if we stretch the thumb, the fore-finger and the central finger of the left hand mutually perpendicular to each other, then if the fore-finger points in the direction of magnetic field, the central finger in the direction of current, then the thumb will point in the direction of motion of the conductor.

Right hand thumb rule : According to this rule, if the linear conductor is grasped in the palm of right hand so that the thumb points in the direction of flow of current, then curling of the fingers will point in the direction of magnetic lines of force.

Maxwell's cork screw rule : According to this rule, if a right handed cork screw is rotated so that it moves in the direction of flow of current through the linear conductor, then direction of rotation of the thumb gives the direction of magnetic lines of force.

Ampere's swimming rule : According to this rule, if we imagine a man to be swimming along the conductor in the direction of flow of current with his face towards the magnetic needle, then the north pole of the magnetic needle will be deflected towards his left hand.

Biot-Savart's law (or Laplace's law) : According to Biot-Savart's law, the magnitude of the magnetic field dB at any point due to a small current element dl is given by,

$$dB = \frac{\mu_o}{4\pi} \cdot \frac{I dl \sin\theta}{r^2}$$

where, I = magnitude of the current flowing.
dl = length of the element.
θ = angle between the length of the element and the line joining the element to point of observation.
r = distance of the point from the element.

Magnetic dipole moment : A circular current loop behaves as a magnetic dipole whose magnetic dipole moment is given by the product of the ampere turns of the coil and its area. Hence, Magnetic dipole moment

$$= \text{Ampere turns} \times \text{Area of the coil}$$
$$= (\text{No. of turns} \times \text{current}) \times \text{Area of the coil}$$
$$= n\text{I} \times \text{A}$$
$$= n\text{IA}$$

Magnetic field due to straight current carrying conductor : The magnitude of magnetic field B at any point at perpendicular distance 'a' from a straight conductor carrying current I is given by,

$$B = \frac{\mu_o}{4\pi} \cdot \frac{I}{a} (\sin \phi_1 + \sin \phi_2)$$

where ϕ_1 and ϕ_2 are the angles which the perpendicular from the point of observation to the conductor makes with the lines joining the two ends of the conductor to the point of observation.

For infinitely long straight conductor,

$$\phi_1 = \phi_2 = \frac{\pi}{2}$$

Hence, $$B = \frac{\mu_o}{4\pi} \cdot \frac{2I}{a}$$

Magnetic field due to current carrying circular coil : The magnitude of magnetic field B on any point on the axis of the circular coil distant x from its centre is given by,

$$B = \frac{\mu_o}{4\pi} \cdot \frac{2\pi n I a^2}{(a^2 + x^2)^{3/2}}$$

where, n = number of turns in the circular coil

I = current flowing through the circular coil

a = radius of the circular coil

Special case :

(i) When point lies at the centre of the coil :

Here $x = 0$,

$$\therefore \ B = \frac{\mu_o}{4\pi} \cdot \frac{2\pi n I}{a}$$

$$= \frac{\mu_o n I}{2a}$$

(ii) When point lies far away from the centre of the coil :

Here $a << x$

$$\therefore \ B = \frac{\mu_o}{4\pi} \cdot \frac{2\pi n I a^2}{x^3}$$

Magnetic field due to current carrying solenoid : The magnitude of the magnetic field B at a point well inside the solenoid is given by,

$$B = \mu_o n I$$

where, n = number of turns per unit length of the solenoid.

I = current flowing through the solenoid.

Magnetic field due to current carrying toroid : The magnitude of the magnetic field B at a point inside the turns of the toroid is given by,

$$B = \mu_o n I$$

where, n = number of turns per unit length of the toroid and

I = current flowing through the toroid.

Force on a current carrying conductor placed in a magnetic field : The magnitude of the force F acting on a current carrying conductor placed in a magnetic field is given by,

$$F = BI\, l \sin\theta$$

where, B = strength of the magnetic field

I = current flowing through the conductor

l = length of the conductor

θ = angle which the conductor makes with the direction of magnetic field.

Force between two infinitely long parallel current carrying conductors : Force per unit length F between two infinitely long parallel current carrying conductors is given by,

$$F = \frac{\mu_o}{4\pi} \cdot \frac{2I_1 I_2}{r}$$

where, I_1 and I_2 = currents flowing through the two conductors.

r = perpendicular distance between the two conductors.

Torque on a current carrying coil placed in a magnetic field : The magnitude of the torque τ on a current carrying rectangular coil placed in a magnetic field B is given by,

$$\tau = nBIA \cos\theta$$

where, n = number of turns in the coil

I = current flowing through the coil

A = area of the rectangular coil

θ = angle which the plane of the coil makes with the direction of the magnetic field.

If the plane coil is parallel to the direction of the magnetic field (i.e., the field is radial).

then $\theta = 0°$ or $\cos\theta = 1$. Hence,

$$\tau = nBIA.$$

Tesla (T) : The SI unit of strength of magnetic field is called as tesla (T). If a charge of one coulomb moving with a velocity of 1 ms^{-1} along a direction perpendicular to the direction of the magnetic field experiences a force of 1 newton, then the strength of magnetic field is called as 1 tesla. Hence,

$$1 \text{ tesla} = \frac{1 \text{ newton}}{1 \text{ coulomb} \times 1 \text{ ms}^{-1}}$$

$$\text{or } 1\text{ T} = \frac{1\text{ N}}{1\text{C} \times 1\text{ ms}^{-1}} = \frac{1\text{ N}}{1\text{ As} \times 1\text{ ms}^{-1}}$$
$$= 1\text{ NA}^{-1}\text{ m}^{-1} = 1\text{ Wb m}^{-2}.$$

Force on a moving charge in a magnetic field : The magnitude of the force F on a charge q moving with a velocity v in a magnetic field B is given by

$$F = qvB \sin\theta$$

where, θ = angle between the direction of v and B.

Force on a charge in a electric field : The magnitude of the force F on a charge q in an electric field E is given by

$$F = qE$$

Lorentz force : The total force experienced by a moving charged particle in both electric and magnetic fields is called Lorentz force. Hence

$$\text{Lorentz force } (\vec{F}) = q\vec{E} + q(\vec{V} \times \vec{B})$$
$$= q(\vec{E} + \vec{V} \times \vec{B})$$

Ampere's circuital law : It states that the line integral of magnetic field $\vec{B}$ around any closed path in vacuum is equal to μ_o times the total current threading the closed path. i.e.,

$$\oint \vec{B} \times d\vec{l} = \mu_o I$$