Thus the electric field due to q is

$$E = \frac{F'}{q'}$$

$$= \frac{\frac{1}{4\pi\mathcal{E}o}\frac{q\,q'}{r^2}r}{q'}$$

i.e

$$E = \frac{1}{4\pi\mathcal{E}o}\frac{q}{r^2}r$$

Or

$$E = \frac{1}{4\pi\mathcal{E}o}\frac{q}{r}\ is\ magnitude\ only$$

<u>Electric field lines (or lines of force)</u>

- Electric fields are represented by field lines
- The line though imaginary represent real field
- Field lines are drawn such that

  The tangent to a field line at a point gives the direction of the field E at that point

  The number of field lines drawn per unit cross-sectional area is proportional to the magnitude of E
- Electric field lines (lines of force):

  Originate from the +ve charge and terminate on –ve charge

  They do not intersect or cross

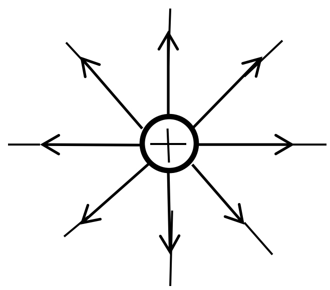
  Where the lines are

  (i) Close together, the field is strong

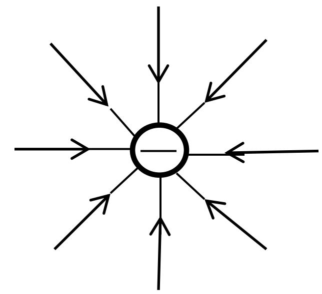
  (ii) Far apart, the field is weak

  (iii) Parallel and equally spaced, the field is uniform.

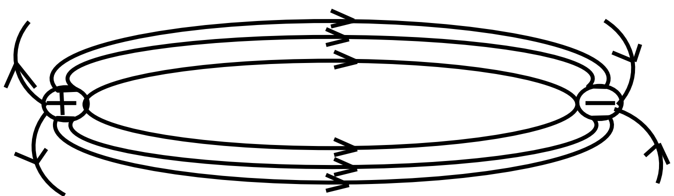
Field lines of point charged



Electric field lines of isolated +ve charge



Electric field lines of isolated -ve charge



Field lines of 2 unlike point charges

Field lines of 2 like point charges

Note: the electric field at a point due to many charges is also determined using the principle of superposition like in case of electric field.

Example

1. Determine the magnitude of the electric field at a point 2.0 m from a point charge of 4.0 nC.

   Solution

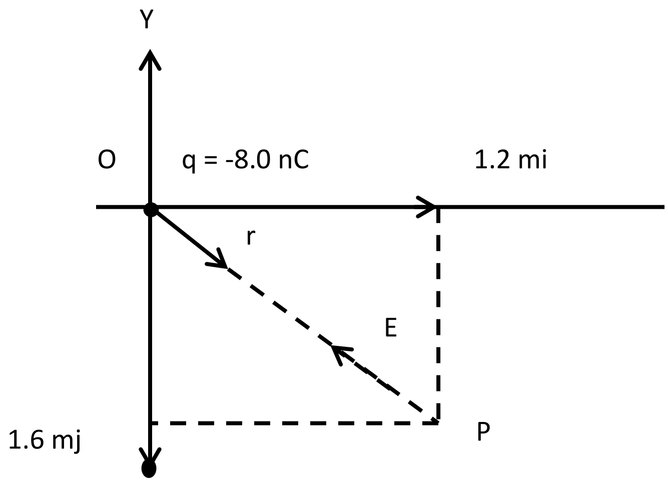
   r= 2.0 m , q = 4.0n C= 4.0 X 10^{-9} C

   $$E = \frac{Kq}{r^2}$$

   $$= \frac{9.0\ X\ 10^9\ X\ 4\ X\ 10^{-9}}{2^2} = 9.0\frac{N}{C}$$

2. A point charge q = - 8n C is located at the origin of a Cartesian coordinate. Determine the electric field vector at the point x=1.2 m and y= -1.6 m

Solution



Sketching the situation, P is the point given by x = 1.2 m and y = -1.6 m.

The distance from the charge to point P is

$r = x_i + y_j$

$r = (1.2_i + (-1.6)_j)\ m$

$= (1.2_i - 1.6_j)$

The magnitude of this distance

$|r| = r = \sqrt{x^2 + y^2}$

$= \sqrt{(1.2)^2 + (-1.6)^2} = 2.0\ m$

The unit vector r is

$r = \frac{r}{r}$

$= \frac{1.2_i - 1.6_j}{2} = 0.6_i - 0.8_j$

Thus the electric field vector

$$E = \frac{Kq}{r^2}\ r$$

$E = \frac{9.0\ X\ 10^2 X\ (-8\ X\ 10^9\ )}{(2)^2}\ X\ 0.6_i - 0.8_j$

$= (-11_i + 14_j)\ N/C$

3. Determine the electric field vector due to an electric dipole at a field point P at a distance r along the perpendicular bisector of the line joining the charges.

- Electric potential is a scalar quantity
  Note: for a potential rise, V will be +ve and the electric potential energy will increase if q is +ve.
- For a potential drop, V will be –ve and the electric potential energy will decrease if q +ve (increase if q is -ve).
- Practical zero potential is that of the earth.
- Theoretical zero potential by definition of V is that of infinity.
- Electron volt: the work done in carrying (moving) an electron through a potential rise of 1 volt is defined as one electron volt (1eV)

Thus;

$1\,eV \;= 1.6\,X\,10^{-19}\,C\,X\,1\,V$

$=\; 1.6\,X\,10^{-19}\,J$

<u>Examples:</u>

How much word is done in carrying an electron from a positive terminal of a 12 v battery to the negative terminal?

<u>Solution</u>

From the +ve to the –ve terminal of the battery, the electron passes through a potential rise is

$V \;=\; +12\,V$

Thus

$W \;=\; qV$

$= -1.6\,X\,10^{-19}\,\mathrm{X}\,12$

$=\; -\,1.92\,X\,10^{-18}\,J$

Each plate has an area = A

Separation between the two plates = d.

1.2 CALCULATING THE CAPACITANCE OF A CAPACITOR.

- ⇨ The capacitance of a giving pair of conductors depends on the geometry of the conductors.
- ⇨ Assume a parallel plate capacitor in which the charged plates (Conductors) are separated by a vacuum (or air) as shown in the figure above.

The surface charge density, δ on either of the plates is given as

$$\delta = {}^{Q}/_{A} \qquad (1.4)$$

Thus the electric field between the plates is given to be

$$E = \frac{\delta}{\xi} = \frac{Q}{\xi A} \qquad (1.5) \text{ From } (1.4)$$

Where ξ = permittivity of free space (vacuum); where value in S.I units is $8{\cdot}85 \times 10^{-12}\ C^2/N.m^2$

Since the field between the plates is uniform (WHY!), the magnitude of the potential difference is giving as

$$\Delta V = Ed = \frac{Qd}{\xi A} \qquad (1.6) \text{ From } (1.5).$$

Substituting EQ (1.6) into EQ (1.2), we obtain

$$C = \frac{Q}{\Delta V} = \frac{Q}{Qd/\xi A} \quad \Rightarrow C = \xi\frac{A}{d} \qquad (1.7).$$

Where A is the area of the plate and d is the separation between the plates.

- ⇨ EQ (1·7) Shows that –

⇨ S.I unit Resistance is

$$\frac{Volt}{Ampere} = \frac{V}{A} = \quad \Omega = Ohm \qquad \left(1\Omega = \frac{1v}{1A}\right)$$

⇨ From Eq. (2.15),

NOW,

⇨ The inverse of conductivity σ is called the RESISTIVITY, ρ.

Thus, from Eq. (2.10)

$V = IR \quad \rightarrow OHM'S\ LAW$

Thus from Eq. (2.10)

$$\rho = \frac{1}{\sigma} = \frac{E}{J} \qquad (2.16)$$

S.I unit of resistivity ρ =(Ω.m) = ohm- meters.

Eq. (2.15) can therefore be written, using Eq. (2.16) as

$$R = \frac{V}{I} = \rho\frac{L}{A} \qquad (2.17)$$

Eq. (2.17) shows that the resistance of any material samples depends on;

(i) the resistivity and (ii) the geometry of the material.

Eq. (2.17) shows that: - the resistance of a given cylindrical conductor is proportional to its length and inversely to its cross- sectional area.

Meaning: - If the length of the wire is doubled, its resistance is also doubled.

If the area of the wire is doubled, its resistance reduces by $\frac{1}{2}$

2.3 RESISTANCE AND TEMPERATURE

Every Ohmic material has a characteristic resistivity that depends on the property of the material and on TEMPERATURE. Thus for a conductor of fixed length, L and cross- sectional area A, the resistivity of the conductor varies approximately linearly with temperature (within limited temp. range) according to the expression:

$$\rho = \rho_0[1 + \alpha(T - T_0)] \qquad (2.18a)$$

Where ρ = Resistivity at some temperature, T (˚C).

P= Resistivity at some reference temperature $T_\circ$ (˚C)

α= Temperature coefficient of RESISTIVITY.

Thus, from Eq. (2.18),

$$\alpha = \frac{1}{\rho_0}\frac{\Delta\rho}{\Delta T} \qquad (2.18b) \qquad => \rho - \rho_\circ = \alpha(T - T_0)]$$

$$\rho - \rho_\circ = \Delta\rho, \qquad (T - T_0) = \Delta T$$

$$\therefore \Delta\rho = \alpha\,\rho_0 \Delta T => = \frac{1}{\rho_0}\frac{\Delta\rho}{\Delta T}$$

Where $\Delta\rho = \rho - \rho_\circ$ = change in Resistivity

$\Delta T = T - T_\circ$ = Temperature interval.

S.I unit of $\alpha = (^\circ C)^{-1}$

Also,

From Eq. (2.17), Resistance is proportional to Resistivity. Hence Eq. (2.18) can also be written as;

$$R = R_0[(T - T_0)] \qquad (2.19)$$

2.4 ENERGY AND POWER IN ELECTRIC CIRCUITS.

- ⇨ Wherever a battery (A source of Emf) is used to establish an electric current in a conductor, the chemical energy stored in the battery is continuously transform into kinetic energy of the charge carriers. This kinetic energy is immediately lost as a result of constant collision between the charge carriers and the atoms of

POWER: - The rate at which the charge loses energy OR

The rate of energy transfer between the circulating charge and the circuit.

$$P = \frac{\Delta V}{\Delta t} = IV \qquad (2.21)$$

Eq. (2.21) is the general expression for the electrical power input or output OR from the load (resistor) between points a and b.

This energy loss by the charge will appear as the internal energy of the load.

- ⇨ S.I unit of power $= \frac{Joules(J)}{Second(s)} = Ampere(A)\ X\ Volt(v)$ = watts

2.5 JOOLE'S LAW OF HEATING

- ⇨ As discussed in section 2.4 from Fig 2:4, the potential energy loss by the moving charges appears as THERMAL ENERGY in the Resistor. The temperature of the resistor thus, rises until the heat flowing out of the resistor equals the energy input to the circuit.
  DEFN: - JOOLE HEATING: - The process by which the potential energy is being dissipated in the Resistor.
  Note: -
  From Eq. (2.15) for a Resistor Eq. (2.21) can be written as:
  $$P = VI = I^2R = \frac{V^2}{R} \qquad (2.22)$$
- ⇨ Eq. (2.22) is known as JOOLE'S LAW; and this power loss is called the I^2R LOSS OR JOULE'S HEATING LOSS.

2.6 ELECTROMOTIVE FORCE (Emf).

Note:- For a conductor to have a steady current, it must be path of a path that forms a complete circuit (closed loop).

Q? => How is steady current maintained in a circuit?

⇨ To maintain a steady direct current, the potential difference must be maintained at a constant rate within the circuit. This is accomplished by a device in the circuit which transport positive charges "uphill" from lower to higher potential energy.

DEFN: - that influence that makes current to flow from a lower potential to a higher potential is called ELECTROMOTIVE FORCE (emf) (see Eq. 2.23)

⇨ S·I unit of emf is the volt (V); where = $1V = \frac{1J}{1C}$

⇨ Emf is represented mathematically as ε

DEFN: - A source of emf is equal to the work done in carrying 1 coulomb of charge through the source.

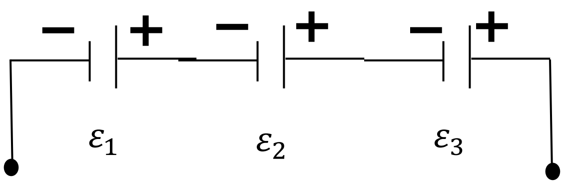
Now, suppose that q coulombs requires an amount of work W joules, the $\varepsilon = \frac{W}{q}$ (2.23a)

Sources of emf include:

1. Batteries or cells – Converts chemical energy into electrical energy.
2. Electric generators – Converts mechanical energy into electrical energy.
3. Thermocouples – Converts heat energy into electrical energy.

⇨ Now, consider the circuit given below.
The potential difference between terminal a and b sets up an electric field within the wire which causes current to flow around the loop from a toward b (from higher to lower potential).

If source of emf are connected in series, as shown below, then the single source of emf which is equivalent to several sources of emf connected in series is given to be



$FIG\ (3.2)$

$$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \ldots \ldots \ldots \ldots \ldots \ldots + \varepsilon_n \qquad (3.5)$$

3.1.2 PARALLEL CIRCUITS.

Let three resistors $\mathrm{R}_{1,}$ $\mathrm{R}_{2,\text{and}}$ R_3be connected as shown:

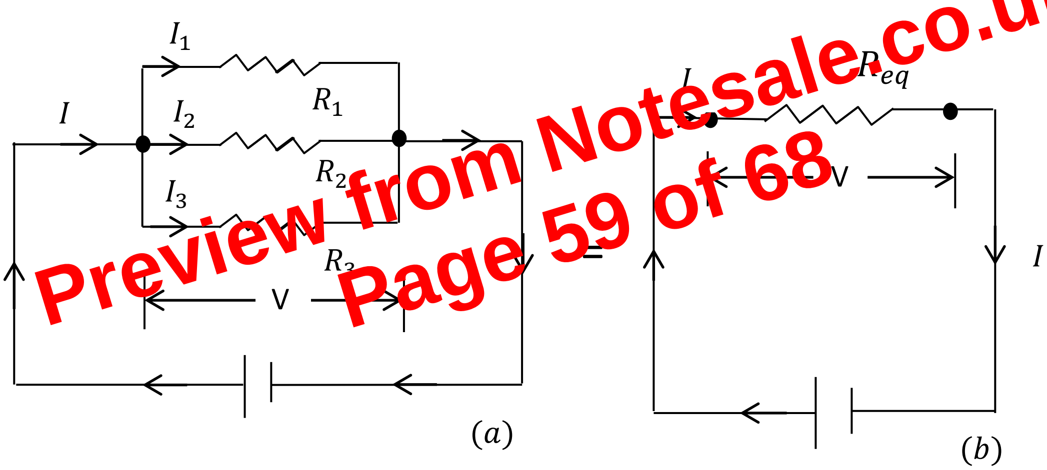


FIG. (3.3)

- ⇨ The basic characteristic future describing the parallel connection of resistors is that, the current through each resistor need not be the same, the potential difference across each of the resistors is the same.
- ⇨ If I is the total current in the circuit, and $\mathrm{I}_1, \mathrm{I}_{2,}\text{and } \mathrm{I}_3$ are the respective current through the resistor $\mathrm{R}_{1,}\mathrm{R}_{2,}$ $\text{and } \mathrm{R}_3$ then

  $$I = \mathrm{I}_1 + \mathrm{I}_2 + \mathrm{I}_3 \qquad (3.6)$$

  But from Ohm's law,

  $$\mathrm{I}_1 = \frac{V}{\mathrm{R}_1} \ , \mathrm{I}_2 = \frac{V}{\mathrm{R}_2} \ , \mathrm{I}_3 = \frac{V}{\mathrm{R}_3} \qquad (3.7)$$

$$-\frac{q}{C} - IR = 0 \tag{3.20}$$

$$=> \ -R\frac{dt}{dt} = \frac{q}{C}$$

$$=> \frac{dq}{dt} = \ -\frac{1}{RC}dt$$

$$=> \ \int_{Q}^{q}\frac{dq}{q} = \ -\frac{1}{RC}\int_{0}^{t}dt \qquad (where\ q = Q\ at\ t = 0)$$

$$=> \ln\left(\frac{q}{Q}\right) = \ -\frac{t}{RC}$$

$$=> q(t) = Qe^{-\frac{1}{RC}} \tag{3.21}$$

(where q= Q at t = o)

Differentiating Eq. (3.21) w.r.t time gives the INSTATENOUS CURRENT as a function of time. i.e

$$I = \frac{dq}{dt} = \frac{d}{dt}\left(Qe^{-\frac{t}{RC}}\right)$$

$$I(t) = \ -\frac{Q}{RC}\ e^{-\frac{t}{RC}} \tag{3.22}$$

$$I(t) = \ -I_0e^{-\frac{t}{RC}}$$

$$where\ I_0 = \frac{Q}{RC} \tag{3.23}$$

The negative sign in Eq. (3.22) indicates that the direction of current as the capacitor discharge is opposite the current direction as the capacitor was being charged.

NOTE: Both the charge on the capacitor and the current decay exponentially at a rate characterized by the time constant $\tau = RC$.