Chapter no: 12

Electrostatics

Numerical Problems:

Problem No 1:

Compare Magnitude of electrical and gravitational forces Exerted on an object (Mass = 10.0 g, Charge = 20.0 µC) by an Identical Object that is Placed 10.0 cm from the first. ($G = 6.67 \times 10^{-11}$ Nm^2 kg^{-2})

Solution:

Given Data:

Mass = $m_1 = m_2$ = 10 gm = 10×10^{-3} Kg

Charge = $q_1 = q_2$ = 20 µC = 20×10^{-6} C

Distance = r = 10 cm = 10×10^{-2} m

To be found:

Electrical Force = F_e =?

Gravitational q_1 Force = F_g =?

Calculations:

We know that

$$F_e = K\frac{q_1 q_2}{r^2}$$

$$= \frac{9\times10^{9} \times20\times10^{-6} \times20\times10^{-6}}{110(10^{-2})^{\,2}}$$

$$= \frac{9\times20\times20\times10^{9-6-6}}{110(10^{-4})}$$

$$= 36 \times 10^{-3+4} = 360 \text{ N}$$

$F_e = 360\ N$

Now, $F_g = G\frac{m_1 m_2}{r^2}$, $G = 6.67 \times 10^{-11}$

$= \frac{6.67 \times 10^{-11} \times 10 \times 10^{-3} \times 10 \times 10^{-3}}{(10 \times 10^{-2})^2}$

$= \frac{6.67 \times 10 \times 10 \times 10^{-11-3-3}}{100 \times 10^{-4}}$

$= 6.67 \times 10^{-17+4}$

$F_g = 6.67 \times 10^{-13}$

Comparison

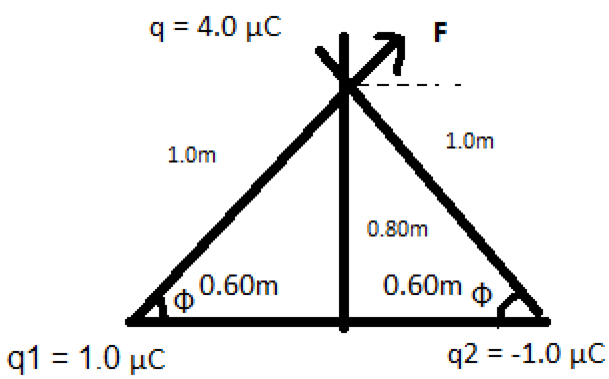
$\frac{F_e}{F_g} = \frac{360}{6.67 \times 10^{-13}}$

$= \frac{360}{6.67 \times 10^{-13}}$

$\frac{F_e}{F_g} = 5.4 \times 10^{14}$

Problem no 2:

Calculate the net Electrostatic force on "q" as shown in figure.



q $= 4\ \mu C = 4 \times 10^{-6}\ C$

$\mathbf{q_1} = 1\ \mu C = 1 \times 10^{-6}\ C$

q_2 = -1 μC = 1×10^{-6} C

To be found:

Net force on q = Force =?

Calculations:

Force on q due to q_1:

$F_1 = K\frac{q_1 q_2}{r^2}$

$= \frac{9 \times 10^9 \times 4 \times 10^{-6} \times 1 \times 10^{-6}}{(1.0)^2}$

$= 9 \times 4 \times 10^{-6-6+9}$

$= 36 \times 10^{-3}$ N

Force on q due to q_2:

$F_2 = K\frac{q_1 q_2}{r^2}$

$F_2 = \frac{9 \times 10^9 \times 4 \times 10^{-6} \times 1 \times 10^{-6}}{(1.0)^2}$

$= 9 \times 4 \times 10^{9-6-6}$

$= 36 \times 10^{-3}$ N

Thus

$F_1 = F_2 = F = 36 \times 10^{-3}$ N

Resolving F_1 and F_2 into components we get:

$F_x = F_{x1} + F_{x2}$

$= F_1 \text{Cos}\,\theta + F_2 \text{ Cos}\,\theta$

$= F\text{Cos}\,\theta + F\text{cos}\,\theta$

$= 2F\cos\Phi$ ---------- (1)

From Figure:

$\tan \boldsymbol{\theta} = \frac{BD}{AD}$

$\tan \boldsymbol{\theta} = \frac{0.80}{0.60} = \frac{4}{3}$

$\boldsymbol{\theta} = \tan^{-1} \frac{4}{3}$

$\boldsymbol{\theta} = 53°$

$F_x = 2F\cos 53°$

$= 2(36 \times 10^{-3})\,(0.6)$

$= 43.2 \times 10^{-3}$

$F_x = 0.0432$ N

And $F_y = F_{1y} - F_{2y}$

$= F_1 \sin \boldsymbol{\theta} - F_2 \sin \boldsymbol{\theta}$

$= F\sin \boldsymbol{\theta} - F\sin\Phi \quad (F_1 = F_2 = F)$

$F_y = 0$N

Magnitude of **F**

$\mathbf{F} = \sqrt{(Fx)^2} + \sqrt{(Fy)^2}$

$= \sqrt{(0.0432)^2} + \sqrt{0^2}$

$= \sqrt{(0.0432)^2}$

$\mathbf{F} = 0.0432$ N

Direction

tan $\boldsymbol{\theta} = \frac{F_y}{F_x} = \frac{0}{F_x} = 0$

tan $\boldsymbol{\theta} = 0$

$\boldsymbol{\theta} = 0$

Thus **F** is along x-axis

F = 0.0432 Ni

Problem: 12.3

A point charge q = - 8.0 × 10^{-9} C is placed at the origin. Calculate electric field at a point 2.0 m from the origin on the z-axis.

Given data:

Charge = q = -8.0 × 10^{-8} C

Distance = r = 2.0m

To be found:

E =?

Calculations:

We know that

$$E = \frac{1}{4\pi\epsilon^{\circ}} \frac{q}{r^2}$$

Putting values, we get:

$$E = 9 \times 10^9 \times \frac{8.0 \times 10^{-8}}{(2)^2}$$

$= \frac{9 \times 8}{4} \times 10^{9-8}$

$= 18 \times 10$

$= 180NC^{-1}$

Since point is on z-axis

E = 180 NC^{-1} $\acute{\kappa}$

Problem 12.4

Dtermine the electric field at position r = (4i + 3j)m caused by a point charge q = 5.0 × 10^{-6} C Placed at origin.

Given Data:

Point charge = q = 5.0 × 10^{-6} C

Position = r = (4**i** + 3**j**) m

To be found:

Electric field at **r = E =?**

Calculations:

We know that:

$$\mathbf{E} = \frac{1}{4\pi\epsilon^\circ}\frac{q}{r^2}$$

r = (4i + 3**j**)

$$\mathbf{r} = \sqrt{(\mathbf{4})^2 + (\mathbf{3})^2}$$

$$= \sqrt{\mathbf{16 + 9}}$$

$$= \sqrt{\mathbf{25}}$$

= 5

And $\mathbf{r} = \frac{\vec{r}}{r} = \frac{4i+3j}{5}$

Putting the values in Equation (1), we get

$\mathbf{E} = 9 \times 10^{9} \times \frac{5 \times 10^{9}}{(5)^2} \times \frac{4i+3j}{5}$

$= \frac{9 \times 10^{9} \times 5 \times 10^{-6}}{25 \times 5}(4\boldsymbol{i}+3\boldsymbol{j})$

$= \frac{9 \times 10^{9-6}}{25}(4\boldsymbol{i}+3\boldsymbol{j})$

$= \frac{9000}{25}(4\boldsymbol{i}+3\boldsymbol{j})$

$= 360(4\boldsymbol{i}+3\boldsymbol{j})$

$\boldsymbol{E} = 1440\boldsymbol{i} + 1080\boldsymbol{j}$

Problem 12.5

Two point charges, $q_1 = -1.0 \times 10^{-6}$C and $q_1 = -1.0 \times 10^{-6}$C, are separated by a distance of 3.0m. Find and justify the zero field location.

Given Data:

Charges = $q_1 = -1.0 \times 10^{-6}$C

Charges = $q_1 = -1.0 \times 10^{-6}$C

Distance = r =3.0m

To be found:

Zero field location = x =?

Calculations:

Let electric intensity at point P_1 at distance x from q_1, is zero, intensity at P due to q_1 is

$E_1 = \frac{1}{4\pi\epsilon^\circ}\frac{q}{r^2}$

Intensity at P due to q_2 is:

$E_2 = \frac{1}{4\pi\epsilon^\circ}\frac{q_2}{(x+3)^2}$

Intensity at P will be zero, if:

$E_1 = E_2$

Putting the Values, we get:

$$\frac{\mathbf{1}}{\mathbf{4\pi\epsilon^\circ}}\frac{\mathbf{q}}{\mathbf{r^2}} = \frac{\mathbf{1}}{\mathbf{4\pi\epsilon^\circ}}\frac{\mathbf{q_2}}{\mathbf{(x+3)^2}}$$

$$\frac{\mathbf{q}}{\mathbf{r^2}} = \frac{\mathbf{q}}{\mathbf{(x+3)^2}}$$

$$\frac{1 \times 10^{-6}}{x^2} = \frac{4 \times 10^{-6}}{(x+3)^2}$$

or

$$\frac{1}{x^2} = \frac{4}{(x+3)^2}$$

Taking square root on both sides we get

$$\frac{1}{x^2} = \frac{2}{x+3}$$

Cross multiplying

x+3 = 2x

2x-x-3 = 0

x-3 = 0

x = 3m

Problem 12.6

Find the electric field strength required to hold suspended a particle of mass 1.0×10^{-6} Kg and charge 1.0μC between two plates 10.0cm apart.

Given Data:

Mass = m = 1.0×10^{-6} Kg

Charge = q = 1.0μC

Separation of plates = d = 10.0cm

= 10×10^{-2} cm

To determine:

Electric intensity = E =?

Calculations:

The particle will be suspended between the plates, when

$F_e = F_g$

or $qE = mg$

$E = \frac{mg}{q}$

Putting the values in above equation

$E = \frac{1 \times 10^{-6} \times 9.8}{1 \times 10^{-6}}$

$E = 9.8\ NC^{-1}$

Or

$E = 9.8 Vm^{-1}$

Problem 12.7

A particle having a charge of 20 electrons on it falls through a potential difference of 100 volts. Calculate the energy acquired by it in electron volts (eV)

Given Data:

Charge = q = 20 e

$= 20 \times 1.6 \times 10^{-9}$

$= 32 \times 10^{-19}$C

Potential difference = ΔV = 100 V

To determine:

Energy required in (eV) = E =?

Calculations:

We know that:

$E = q\Delta V$

$= (32\times 10^{-19})(100)$

$= 3200 \times 10^{-19}$ Joules

Since 1eV = 1.6×10^{-19}C

$\therefore\ E = \frac{3200 \times 10^{-19}\ J}{1.6 \times 10^{-19}}$

$= \frac{3200}{1.6}$

= 2000eV

$E = 2 \times 10^{3}$eV

Problem 12.8

In the Millikan's experiment, oil droplets are introduced into the space between two flat horizontal plates, 500 mm apart. The plate voltage is adjusted to exactly 780V so that the droplet is held stationary. The plate voltage is switched off t and he selected droplets is observed to fall a measured distance of 1.50 mm in 11.2 s. Given that the density of the oil used is 900kgm^{-3}, and the viscosity of air at laboratory temperature is 1.80 × 10^{-5}Nm^{-5}s, calculate:

a) the mass, and
b) the charge on the droplet (assume g = 9.8 ms^{-2})

Solution:

Given data:

Distance between plates = d = 500 mm = 500×10^{-3}

Potential difference = V = 780 V

Distance covered = S = 1.50mm = 1.5×10^{-3}

Time = t = 11.2 s

Density of oil = ρ = 900kg/m^3

Viscosity = ŋ = 1.8×10^{-5} Nm^{-2}s

To determine:

Mass = m =?

Charge on droplet = q =?

Calculations:

We know that:

Density = $\frac{Mass}{Volume}$

Mass = (volume) (Density)

m = $\frac{4}{3}\pi\pi^{3}\times\rho$ ---------- (1)

Calculation for r:

Terminal velocity = $v_T = \frac{S}{t}$

$= \frac{1.5\times10^{-3}}{11.2}$

$= 0.134 \times 10^{-3}$ m/s

and r = $\sqrt{\frac{9\,\eta\,V_T}{2\rho g}}$

$= \sqrt{\frac{9\times1.8\times10^{-5}\times1.34\times10^{-3}}{2\times900\times9.8}}$

$= \sqrt{\frac{9\times1.8\times1.34\times\ 10^{-5-3}}{2\times900\times9.8}}$

$= \sqrt{\frac{9\times1.8\times1.34}{2\times900\times9.8}}\times10^{-4}$

$= 0.011 \times 10^{-4}$ m

Now putting values of r in eq.(1)

m = $\frac{4}{3}$(3.14) $(0.011 \times 10^{-4})^{-3}\times 900$

$= 4\,(3.14) \times (1.3 \times 10^{-6} \times 10^{-12}) \times 300$

$= 4\,(3.14) \times (1.33) \times (300) \times 10^{-18}$

$= 5015.0 \times 10^{-18}$ kg

$= 5.01 \times 10^{-15}$ kg

$m = 5.01 \times 10^{-15}$ kg

Charge on droplet:

Since the charge is suspended between the plates

$\therefore F_e = F_g$

$qE = mg$

$q = \frac{mg}{E}$

But $V = Ed$

$E = \frac{d}{V}$

$\therefore\ q = \frac{mg}{V/d}$

$q = \frac{mgd}{V}$

Putting values, we get

$q = \frac{5.01 \times 10^{-15} \times 9.8 \times 5 \times 10^{-3}}{780}$

$= \frac{0.315 \times 10^{-18}}{780}$

$= 0.315 \times 10^{-18}$

$= 3.15 \times 10^{-19}$ C

$q = 3.15 \times 10^{-19}$C

Problem: 12.9

A proton place in uniform electric field of 5000 NC^{-1} directed to right is allowed to go a distance of 10.0 cm from A to B. Calculate:

a) potential difference between two points
b) work done
c) the change in P.E of proton
d) the change in K.E of the proton
e) Its velocity (mass of proton is 0.67×10^{-27})

Given Data:

Electric field = E = $5000NC^{-1}$

Distance = d = 10.0 cm = 10×10^{-2}

To determined:

Potential difference = V =?

Work done = W =?

The change in P.E of proton =?

The change in K.E of the proton =?

Velocity of Proton = V =?

Calculations:

Potential difference is given by

$V = -Ed$

$= -(500) \times (10 \times 10^{-2}) = -500V$

V = -500V

As proton moves from higher to lower potential

Work Done: $q\Delta V$

$= 1.6 \times 10^{-19} \times 500\ j$

$= \frac{1.6 \times 10^{-19} \times 500\ j}{1.6 \times 10^{-19}}\ eV$

$\Delta V = 500eV$

Change in P.E = loss of P.E.

= Workdone

i.e., Δ P.E = -500eV

Negative sign shows loss of P.E.

Change in K.E = Gain in K.E

= loss in P.E

I.e. Δ K.E = 500eV

Velocity =?

Since

K.E = $\frac{1}{2}mv^2$

$mv^2 = 2$ K.E

$v^2 = \frac{2\ K.E}{m}$

$v^2 = \frac{2 \times 500 \times 1.6 \times 10^{-19}}{1.67 \times 10^{-27}}$

$v^2 = 958.08 \times 10^8$

$v = 3.0 \times 10^5$ m/s

Problem: 12.10

Using zero reference point at infinity, determine the amount by which a point charge of 4.0 × 10^{-8}C alters the electric potential at a point 1.2 m away, when a) charge is positive b) Charge is negative

Given Data:

Charge = q = 4.0 × 10^{-8}C

Distance = r = 1.2 m

To determined:

Electric Potential = V=?

Calculations:

When charge is positive

$$V = \frac{1}{4\pi\epsilon_\circ}\frac{q}{r}$$

Putting the values, we get:

$$V = 9 \times 10^9 \times \frac{4 \times 10^{-8}}{1.2}$$

$$= \frac{9 \times 4}{1.2} \times 10^{9-8}$$

$$= 30 \times 10$$

$V = 300V$

When charge is Negative:

$$V = \frac{1}{4\pi\epsilon_\circ}\frac{-q}{r}$$

$= 9 \times 10^9 \times \frac{-4 \times 10^{-8}}{1.2}$

$= \frac{9 \times -4}{1.2} \times 10^{9-8}$

$= -30 \times 10$

$V = -300V$

Problem: 12.11

In Bohr's atomic model of hydrogen atom, the electron is in an orbit around the nuclear proton at a distance of 5.29×10^{-11} m with a speed of $2.18 \times 10^6\ ms^{-1}$.

a) **The electric potential that a proton exerts at this distance**
b) **Total energy of the atom in eV**
c) **The ionization energy for the atom in eV**

Give data:

Distance = r = 5.29×10^{-11} m

Velocity = V = $2.18 \times 10^6\ ms^{-1}$

Charge of Electron = e = 1.6×10^{-19} C

Mass of Electron = 9.1×10^{-31} kg

To determine:

a) Electric potential = V =?
b) Total energy in eV = E_n =?
c) Ionization energy in eV =?

Calculations:

Electric potential at r is given by

$V = \frac{1}{4\pi\epsilon_\circ}\frac{q}{r}$

Putting the values

$V = 9 \times 10^9 \times \frac{1.6 \times 10^{-19}}{5.29 \times 10^{-11}}$

$= \frac{9 \times 1.6}{5.29} \times 10^{9-19+11}$

$= 2.72 \times 10$

$= 27.2$ volts

Total energy in eV

Total energy is given by

E = K.E + P.E

Now

$K.E = \frac{1}{2}mv^2$

Putting the values

$= \frac{1}{2}(9.7 \times 10^{-31}) \times (2.18 \times 10^6)^2$

$= 4.55 \times 2.18 \times 2.18 \times 10^{-19}$ J

$K.E = \frac{4.55 \times 2.18 \times 2.18 \times 10^{-19}}{1.6 \times 10^{-19}}$

K.E = 13.51 eV

And

$P.E = -Ve = -(27.2) \times (1.6 \times 10^{-19})$J

$$= -\frac{27.2 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19}}$$

P.E = -27.2 eV

Putting the values in E = K.E + P.E

E = 13.51 + (-27.2)

E = -13.6 eV

Ionization energy

We know that:

Ionization energy = E_∞ + E_G

= 0 – (-13.6 eV)

= 13.6 eV

Therefore, if we want to ionize hydrogen atom then we must supply an amount of 13.6 eV from some external source.

∴ Ionization energy = 13.6 eV

Problem no: 12.12

The electronic flash attachment for a camera contains a capacitor for storing the energy used to produce the flash. In one such unit, the potential difference between the plates of a 750μF capacitor is 300V. Determine the energy that is used to produce the flash.

Given Data:

Potential Difference = V = 330 volts

Capacitance = C = 750 μF

To determine:

Energy stored = E =?

Calculations:

We know that

$$E = \frac{1}{2}CV^2$$

Putting values, we get:

$$E = \frac{1}{2}(750 \times 10^{-6}) \times (330)^2$$

$$= \frac{1}{2} \times 750 \times 10^{-6} \times 108900$$

$$= 40.8\ J$$

$$E = 40.8\ J$$

Problem no: 12.13

A capacitor has a capacitance of 2.5×10^{-8} F. In the charging process, electrons are removed from one plate and placed on the other one. When the potential difference between the plates is 450 V, how many electrons have been transferred?

Given Data:

Capacitance = C = 2.5×10^{-8} F

Potential Difference = V = 450V

Charge on Electrons = e = 1.6×10^{-19}C

To determine:

No of electrons = n =?

Calculations:

We know that

$Q = CV$ ------- (1)

We also know that:

$Q = ne$ ----- (2)

From (1) to (2)

$ne = CV$

$$n = \frac{CV}{e}$$

Putting values, we get:

$$n = \frac{2.5 \times 10^{-8} \times (450)}{1.6 \times 10^{-19}}$$

$$= \frac{2.5 \times 450}{1.6} \times 10^{-8+19}$$

$$= 70.2 \times 10^{11}$$

$n = 7.0 \times 10^{11}$ electrons