PROBLEMS

P.12.1 Compare magnitudes 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. ($G = 6.67\times10^{-11}\ Nm^2\,kg^{-2}$).

SOLUTION :-

Data

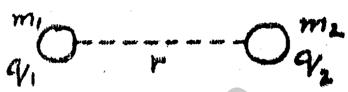
$m_1 = m_2 = 10\,g = 0.01\,kg$

$q_1 = q_2 = 20\mu C = 20\times10^{-6}\,C$

$r = 10\,cm = 0.1\,m$

$F_e = ?$

$F_g = ?$



Calculation :-

$$F_e = \frac{1}{4\pi\epsilon_0}\,\frac{q_1 q_2}{r^2}$$

$$= \frac{9\times10^{9}\times20\times10^{-6}\times20\times10^{-6}}{(0.1)^2}\ N$$

$$F_e = 360\,N \quad \text{———} \ (1)$$

and

$$F_g = G\,\frac{m_1 m_2}{r^2}$$

$$= \frac{6.67\times10^{-11}\times0.1\times0.1}{(0.1)^2}\ N$$

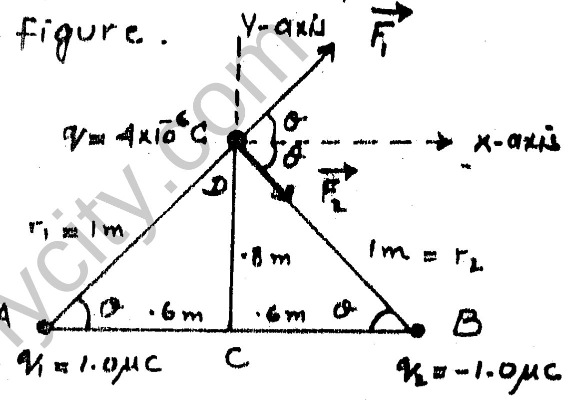
$$F_g = 6.67 \times 10^{-13}\ N \quad \text{——— ②}$$

Dividing eq ① by ② we get

$$\frac{F_e}{F_g} = \frac{360\ N}{6.67 \times 10^{-13} N} = 5.4 \times 10^{14}$$

This shows that electric force between given charges is 5.4×10^{14} times greater than gravitational force.

P 12.2 Calculate the net electrostatic force on q as shown in figure.



Solution :-

Data :-

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

$q_2 = -1.0 \times 10^{-6}$ C

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

$r_1 = 1m$

$r_2 = 1m$

$AC = BC = 0.6\ m$

$AD = BD = 1m$

$CD = 0.8\ m$

Calculations

From the Δ CAD

$$\tan\theta = \frac{CD}{AC} = \frac{0.8}{0.6} = \frac{4}{3}$$

$$\theta = \tan^{-1} 4/3 = 53^\circ$$

$$F_1 = \frac{1}{4\pi\epsilon_0}\frac{q_1 q}{r^2} = \frac{9\times10^9 \times 1\times10^{-6} \times 4\times10^{-6}}{(1)^2}\ N$$

$$= 3.6 \times 10^{-2}\ N$$

and

$$F_2 = \frac{1}{4\pi\epsilon_0}\frac{q_2 q}{r^2} = \frac{9\times10^9 \times 1\times10^{-6} \times 4\times10^{-6}}{(1)^2}\ N$$

$$F_2 = 3.6 \times 10^{-2}\ N$$

Resolving $\vec{F_1}$ and $\vec{F_2}$ into its components.

$$F_{1x} = F_1 \cos\theta = 3.6\times10^{-2} \cos 53^\circ = 0.02167\ N$$

$$F_{2x} = F_2 \cos\theta = 3.6\times10^{-2} \cos 53^\circ = 0.02167\ N$$

$F_{1y} = F_1 \sin\theta = 3.6\times10^{-2} \sin 53^\circ = 0.0287\ N$

$F_{2y} = -F_2 \sin\theta = -3.6\times10^{-2} \sin 53^\circ = -0.0287\ N$

Let F_x and F_y be the components of the resultant force F.

$$\vec{F} = F_x\hat{i} + F_y\hat{j} \quad \text{———} \quad (1)$$

$$F_x = F_{1x} + F_{2x} = 0.02167N + 0.02167N$$

$$F_x = 0.04334\ N$$

and

$$F_y = F_{1y} + F_{2y} = 0.0287 - 0.0287N$$

$$F_y = 0$$

Putting values of F_x and F_y in eq (1)

$$\vec{F} = 0.043\,\hat{i}\,N + 0\hat{j}$$

$$\boxed{\vec{F} = 0.043\,\hat{i}\ N}$$

12.3 A point charge $q = -8.0\times10^{-8}$ C is placed at origin. Calculate electric field at point 2.0 m from the origin on z-axis.

Solution

Data:- $q = -8.0\times10^{-8}C$

$r = 2.0\ m$

$E = ?$

Calculations

As

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

$$E = \frac{9\times10^{9}\times 8\times10^{-8}}{(2)^2} NC^{-1}$$

$$E = 1.8\times10^{2} NC^{-1}$$

Along z-axis

$$\vec{E} = E\hat{k}$$

$$\vec{E} = (1.8\times10^{2}\hat{k})NC^{-1}.$$

P. 12.4 Determine the electric field at the position $\vec{r} = (4\hat{i} + 3\hat{j})$ m caused by a point charge $q = 5.0 \times 10^{-6}$ C placed at origin.

Solution:-

$$\vec{r} = (4\hat{i} + 3\hat{j})\ \hat{m}$$

$$q = 5.0 \times 10^{-6}\ C.$$

$$r = \sqrt{4^2 + 3^2} = 5\ m$$

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

As $$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

$$= \frac{9\times10^9 \times 5\times10^{-6}}{5^2} \times \frac{4\hat{i}+3\hat{j}}{5}$$

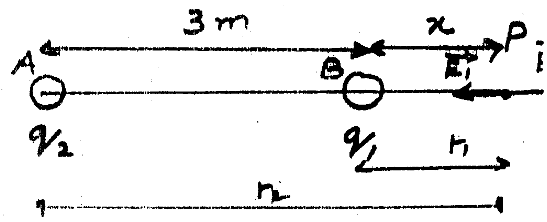
$$\vec{E} = (1440\hat{i} + 1080\hat{j})\ NC^{-1}$$

P.12.5 Two point charges $q_1 = -1.0\times10^{-6}$ C and $q_2 = 4.0\times10^{-6}$ C, are separated by a distance of 3.0 m. Find and justify the zero field location.

Solution $q_1 = -1.0\times10^{-6}$ C

$q_2 = 4.0\times10^{-6}$ C

$AB = 3.0$ m



from figure

$r_1 = (x)$ m

$r_2 = (3+x)$ m

Since q_1 is a $-$ve charge so the field produced by it will be attractive for a test charge q_0 placed at 'P' while q_2 is a +ve charge so field will be repulsive.

Both the fields are acting in opposite directi[on]. The resultant field will be zero if both will have same magnitudes.

So $E_1 = E_2$ As $E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$

$$\frac{1}{4\pi\epsilon_0}\frac{q_1}{r_1^2} = \frac{1}{4\pi\epsilon_0}\frac{q_2}{r_2^2}$$

$$\frac{1}{4\pi\epsilon_0} \times \frac{1\times10^{-6}}{x^2} = \frac{1}{4\pi\epsilon_0} \times \frac{4\times10^{-6}}{(x+3)^2}$$

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

$$(x+3)^2 = 4x^2$$

$$x^2 + 6x + 9 = 4x^2$$

or $3x^2 - 6x - 9 = 0$

or $x^2 - 2x - 3 = 0$

$$x^2 - 3x + x - 3 = 0$$

$$x(x-3) + 1(x-3) = 0$$

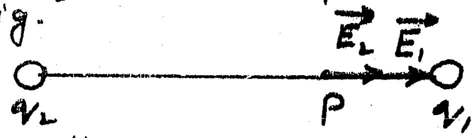
$$(x-3)(x+1) = 0$$

Either $x - 3 = 0$ or $x + 1 = 0$

$x = 3\,m$ or $x = -1\,m$

The –ve distance indicates that point 'P' is lying to the left of the point charge q_1 as shown in fig.

In this case electric intensity at pt. P will be in the same directions So resultant field will be sum of $\vec{E_1}$ & $\vec{E_2}$ but not zero.



$\therefore$ Correct answer is $x = 3\,m$

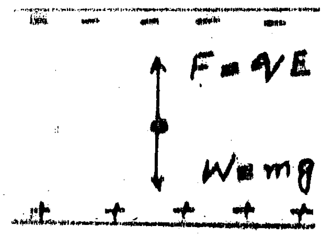
P 12.6 Find the electric field strength required to hold suspended a particle of mass 1.0×10^{-6} kg and charge $1.0\,\mu C$ between two plates 10.0 cm apart.

Solution $q_1 = 1.0\,\mu C = 1.0\times10^{-6}\,C$

$m = 1.0\times10^{-6}$ kg

$d = 10.0\,cm = 0.1\,m$

When a charge is placed b/w two parallel oppositely charged plates then two forces acts on it



If $F_E = W$ then charge will be suspended.

So $qE = mg$

$$E = \frac{mg}{q} = \frac{1.0\times10^{-6}\,kg \times 9.8\,ms^{-2}}{1.0\times10^{-6}\,C}$$

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

P-12.7 A particle having a charge of 20 electrons on it falls through a potential diff. of 100 volts. Calculate the energy acquired by it in eV.

Solution:-

$n = 20$ electrons

$e = 1.6\times10^{-19}\,C$

So $q = ne = 20\times1.6\times10^{-19}\,C$

$\Delta V = 100$ volts

So $K.E = q\,\Delta V$

$= 20\times1.6\times10^{-19}\times100$

$1\,eV = 1.6\times10^{-19}\,J$

So $K.E = \frac{20\times1.6\times10^{-19}\times100}{1.6\times10^{-19}}$

$K.E = 2000\,eV$

P-12.8 :- In Millikan's experiment, oil droplets are introduced into the space b/w two flat horizontal plates 500 mm apart. The plate voltage is adjusted to exactly 780 V so that the droplet is held stationary. The plate voltage is switched off and the selected droplet is observed to fall a measured distance of 1.50 mm in 11.2 s. Given that the density of the oil used is $900\ kg\,m^{-3}$, and the viscosity of air at laboratory temperature is $1.80 \times 10^{-5} N m^{-2} s$ Calculate

(a)- The mass and

(b)- The charge on the droplet.

Solution :-

$d = 5mm = 5 \times 10^{-3} m$

$V = 780$ volts.

$s = 1.55mm = 1.55 \times 10^{-3} m$

$t = 11.2 s$

$\eta = 1.8 \times 10^{-5} N m^{-2} s$

$\rho = 900 kg m^{-3}$

$m = ?$

$q = ?$

(a)- Mass As $m = \frac{4}{3} \pi r^3 \rho$ ——— (1)

$V_t = S/t = \frac{1.55 \times 10^{-3}}{11.2} = 0.1339 \times 10^{-3} m s^{-1}$.

As $r = \sqrt{\frac{9 \eta V_t}{2 \rho g}}$

$= \sqrt{\frac{9 \times 1.8 \times 10^{-5} \times 0.1339 \times 10^{-3}}{2 \times 900 \times 9.8}}$ m

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

Putting values in eq (1)

$m = \frac{4}{3} \times 3.142 \times (0.011 \times 10^{-4})^3 \times 400$ kg

$m = 5.018 \times 10^{-15}$ kg

(b)- Charge

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

$= \frac{5.018 \times 10^{-15} \times 9.8 \times 5 \times 10^{-3}}{780}$ C

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

5 b)

P. 12.9 A proton placed in a 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

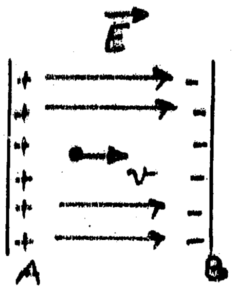
(a). Pot. diff. b/w two pts.

(b). Work done

(c). The change in P.E of proton

(d). " " " K.E " "

(e). Its velocity.



Solution:-

$q = 1.6 \times 10^{-19}\ C$

$m = 1.67 \times 10^{-27}\ kg$

$E = 5000\ NC^{-1}$

$d = 0.1\ m$

(a). As $V = -Ed$

$= -5000\ NC^{-1} \times 0.1\ m$

$V = -500$ volts.

(b).

$Work = qV$

$= 1.6 \times 10^{-19}\ C \times 500$ Volts.

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

$Work = 500\ eV$

$(\because 1\ eV = 1.6 \times 10^{-19}\ J)$

(C).

$\Delta U = qV$

$= 1.6 \times 10^{-19}\ C \times -500$ volts.

$\Delta U = -500\ eV$

–ve sign shows that P.E is decreasing.

(d). $\Delta K.E = qV$

$= 1.6 \times 10^{-19}\ C \times 500$ volts.

$\Delta K.E = 500\ eV$

(e). $\Delta K.E = \frac{1}{2} m v^2$

$v = \sqrt{\frac{2\,\Delta K.E}{m}} = \sqrt{\frac{2 \times 500 \times 1.6 \times 10^{-19}}{1.67 \times 10^{-27}}}$

$v = 3.097 \times 10^{5}\ m s^{-1}$

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 +ve (b) Charge is −ve.

Solution :-

$q = 4 \times 10^{-8}$ C

$r = 1.2$ m

(a) As

$$V_1 = \frac{1}{4\pi\epsilon_o}\frac{(+q)}{r}$$

$$= \frac{9\times10^{9} \times 4\times10^{-8}}{(1.2)} = +300 \text{ volts}$$

The +ve sign indicates that charge is moving against the direction of repulsive force.

(b)-

$$V_2 = \frac{1}{4\pi\epsilon_o}\frac{(-q)}{r}$$

$$= \frac{9\times10^{9} \times 4\times10^{-8}}{1.2} = -300 \text{ volts}$$

Negative sign indicates that the charge is moving along the direction of the force of attraction.

12.11 In Bohr's atomic model of H-atom, the electron is in an orbit around the nuclear proton at a distance of 5.29×10^{-11} m with a speed of 2.18×10^{6} m s^{-1}. Find
(a). The electric pot. at this distance
(b). Total energy of the atom in eV.
(c). The ionization energy for atom in eV.

Solution :-

$r = 5.29\times10^{-11}$ m

$v = 2.18\times10^{6}$ m s^{-1}

$e = 1.6\times10^{-19}$ C

$m = 9.1\times10^{-31}$ kg

(a)

$$V = \frac{1}{4\pi\epsilon_o}\frac{q}{r} = \frac{9\times10^{9}\times1.6\times10^{-19}}{5.29\times10^{-11}} \text{ volts}$$

$$V = 27.22 \text{ volts}$$

(b)- The total energy of an electron in nth orbit is

$$\text{Energy} = -\frac{Ke^2}{2r_n} = \frac{1}{2}mv^2 + q\Delta V \quad (K.E + P.E)$$

$$\frac{1}{2}mv^2 = eV$$

for this case

$$\text{Energy} = -\frac{9\times10^9\times(1.6\times10^{-19})^2}{2\times5.29\times10^{-11}}$$

$$= -2.1777\times10^{-18}\ J$$

$$= \frac{-2.1777\times10^{-18}}{1.6\times10^{-19}}\ eV$$

$$\text{Energy} = \underline{-13.6\ eV}$$

(c)- As electron possess 13.6 e.v energy in the ground state of a H-atom. If we want to ionize it we must apply 13.6 e.v energy from some external source or it is accelerated through a p.diff of 13.6 volts. i.e

$$\text{Energy} = qV$$

$$= 1.6\times10^{-19}\times13.6\ J$$

$$= \frac{1.6\times10^{-19}\times13.6}{1.6\times10^{-19}}\ eV$$

$$\text{Ionization. E.} = \underline{13.6\ e.V}$$

P.12.12 :- The electric flash attachment for a camera contains a capacitor for storing the energy used to produce the flash. In one such unit the pot. diff b/w the plates of 750 μF capacitor is 330 V. Determine the energy that is used to produce the flash.

Solution :- $C = 750\mu F = 750\times10^{-6}\ F$

$V = 330\ V$

$$\text{Energy} = \frac{1}{2}CV^2$$

$$= \frac{1}{2}\times750\times10^{-6}\times(330)^2$$

$$\text{Energy} = \underline{40.83\ J}$$

P.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 pot. diff. b/w the plates is 450V, how many electrons have been transferred?

Solution :-

$$C = 2.5 \times 10^{-8}\ F$$
$$V = 450V$$
$$e = 1.6 \times 10^{-19}\ C$$
$$n = ?$$

As

$$Q = CV$$
$$= 2.5 \times 10^{-8}\ F \times 450V$$
$$= 1125 \times 10^{-8}\ C$$

$$\text{no. of } e^{-}\text{s} = n = \frac{Q}{e} = \frac{1125 \times 10^{-8}}{1.6 \times 10^{-19}}$$

$$n = 703 \times 10^{11}$$

or

$$\boxed{n = 7.03 \times 10^{13} \text{ electrons.}}$$