CHAPTER NO. 12(ELECTROSTATICS)

Question 12.1:- Compare magnitudes of electrical and gravitational forces 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 x 10^{-11} N m^2 kg^{-2})

Solution:- Mass = $m_1 = m_2$ = 10.0 g = 0.01 kg

Charge = $q_1 = q_2$ = 20.0 μC = 20.0 x 10^{-6} C = 2.0 x 10^{-5} C

Distance = r = 10.0 cm = 0.10 m

$F_e = k\frac{q_1 q_2}{r^2}$ where k = 9 x 10^9 N m^2 C^{-2}

$F_e = (9 \times 10^9)\frac{(2.0 \times 10^{-5})(2.0 \times 10^{-5})}{0.10^2} = 3.6 \times 10^2$ N

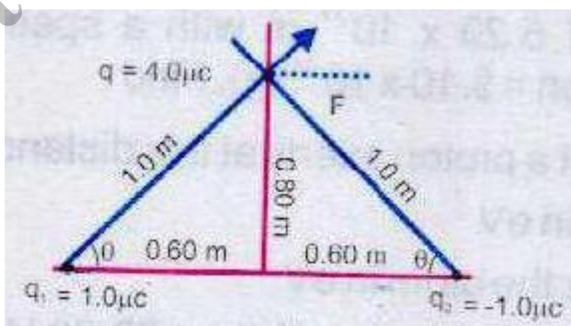
$F_g = G\frac{m_1 m_2}{r^2} = (6.67 \times 10^{-11})\frac{(0.01)(0.01)}{0.10^2} = 6.67 \times 10^{-13}$ N

We can compare F_e with F_g by taking ratio as under:-

$\frac{F_e}{F_g} = \frac{3.6 \times 10^2}{6.67 \times 10^{-13}} = 0.54 \times 10^{15}$

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

Question 12.2:- Calculate vectorially the net electrostatic force on q as shown in the figure.



Solution:- q_1 = 1.0 μC = 1.0 x 10^{-6} C

q_2 = -1.0 μC = - 1.0 x 10^{-6} C

q = 4.0 μC = 4.0 x 10^{-6} C

We can see from the diagram that $|\vec{r_1}| = |\vec{r_2}| = r$ = 1.0 m

$\vec{r_1} = (0.60\hat{\imath} + 0.80\hat{\jmath})$ m

$\vec{r_2} = (0.60\hat{\imath} - 0.80\hat{\jmath})$ m

Since $|\vec{r_1}| = |\vec{r_2}|$ = r = 1.0 m so we can say that $\hat{r_1} = \vec{r_1}$ & $\hat{r_2} = \vec{r_2}$

The net force on q is vector sum of the forces applied by q_1 and q_2.

$\vec{F_1} = k\frac{q_1 q}{{r_1}^2}\hat{r_1}$

$\vec{F_2} = k\frac{q_2 q}{{r_2}^2}\hat{r_2}$

$\vec{F} = \vec{F_1} + \vec{F_2}$

$\vec{F} = k\frac{q_1 q}{{r_1}^2}\hat{r_1} + k\frac{q_2 q}{{r_2}^2}\hat{r_2}$

$\vec{F} = (9 \times 10^9)\frac{(1.0 \times 10^{-6})(4.0 \times 10^{-6})}{(1.0)^2}(0.60\hat{\imath} + 0.80\hat{\jmath}) + (9 \times 10^9)\frac{(1.0 \times 10^{-6})(4.0 \times 10^{-6})}{(1.0)^2}(0.60\hat{\imath} - 0.80\hat{\jmath})$

$\vec{F} = (0.036)\,(0.60\hat{\imath} + 0.80\hat{\jmath}) + (0.036)\,(0.60\hat{\imath} - 0.80\hat{\jmath}) = 0.04\,\hat{\imath}$ N

$\vec{F} = 0.04\,\hat{\imath}$ N

Question 12.3:- A point charge q = -8.0 x 10^{-8} C is placed at the origin. Calculate electric field at a point 2.0 m from the origin on the z-axis.

Solution:- Charge = q = -8.0 x 10^{-8} C

Distance = r = 2.0 m

$\vec{E} = k\,\frac{q}{r^2}\,\hat{r} = (9 \times 10^9)\,\frac{(-8.0 \times 10^{-8})}{(2.0)^2}\,\hat{k}$

$\vec{E} = (-1.8 \times 10^2\,\hat{k})$ N C^{-1}

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

Solution:- Charge = q = 5.0 x 10^{-6} C

Position vector = $\vec{r} = (4\hat{\imath} + 3\hat{\jmath})$ m

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

Unit vector = $\hat{r} = \frac{\vec{r}}{r} = \frac{4\hat{\imath} + 3\hat{\jmath}}{5}$

$\vec{E} = k\,\frac{q}{r^2}\,\hat{r} = (9 \times 10^9)\,\frac{(5.0 \times 10^{-6})}{(5)^2}\,(\frac{4\hat{\imath} + 3\hat{\jmath}}{5}) = (360)(4\hat{\imath} + 3\hat{\jmath})$

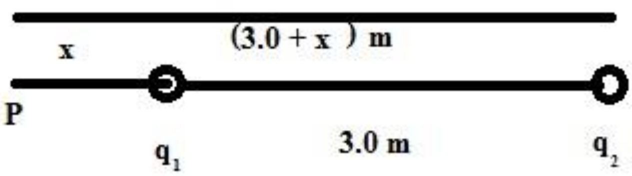
$\vec{E} = (1440\hat{\imath} + 1080\hat{\jmath})$ N C^{-1}

Question 12.5:- Two point charges q_1 = -1.0 x 10^{-6} C and q_2 = +4.0 x 10^{-6} C, are separated by a distance of 3.0 m. Find and justify the zero-field location.

Solution:- q_1 = -1.0 x 10^{-6} C

q_2 = +4.0 x 10^{-6} C

Distance = 3.0 m



Suppose q_1 and q_2 are placed horizontally 3.0 m apart as shown in figure. Electric field cannot be zero between these two opposite charges. It is zero either on a point left side of q_1 or on right side of q_2 because fields of both charges are in opposite direction on these points. In this case magnitude of q_1 is less than q_2, therefore, zero-field location lies near q_1 i.e. on left side of q_1.

Consider a point P on left side of q_1 at a distance x. Electric fields due to q_1 and q_2 on this point are in opposite direction. The net electric field on this point will be zero if electric fields due to q_1 and q_2 on this point are equal in magnitude.

$E_1 = E_2$

$k\,\frac{q_1}{r_1^2} = k\,\frac{q_2}{r_2^2}$

We can see that r_1 = x and r_2 = 3 + x

$$\frac{1.0 \, x \, 10^{-6}}{x^2} = \frac{4.0 \, x \, 10^{-6}}{(3+x)^2}$$

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

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

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

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

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

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

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

x = - 1.0 m & 3.0 m

We can choose x = 3.0 m as negative distance is neglected.

Electric field is zero at distance of 3.0 m on left side of q_1.

Question 12.6:- Find the electric field strength required to hold suspended a particle of mass 1.0×10^{-6} kg and charge 1.0 μC between two plates 10.0 cm apart.

Solution:- Mass = m = 1.0×10^{-6} kg

Charge = q = 1.0 μC = 1.0×10^{-6} C

Distance = d = 10.0 cm = 0.1 m

The particle will suspend if the magnitudes of gravitational force (weight) acting downwards will be equal to magnitude of electric force acting upwards.

$F_e = F_g$

qE = mg

$$E = {mg}/{q} = \frac{(1.0 \, x \, 10^{-6})(9.8)}{(1.0 \, x \, 10^{-6})}$$

$E = 9.8 \; V \, m^{-1} = 9.8 \; N \, C^{-1}$

Question 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).

Solution:- Charge = q = 20 e

Potential difference = ΔV = 100 V

Energy = W = q ΔV = (20 e) (100 V)

W = 2000 eV

$W = 2.0 \times 10^3$ eV

Question 12.8:- In Millikan's experiment, oil droplets are introduced into the space between two flat horizontal plates, 5.00 mm apart. The plate voltage is adjusted to exactly 780 V so that 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 oil used is

900 kg m^{-3}, and the viscosity of air at the laboratory temperature is 1.80 x 10^{-5} N m^{-2} s, calculate a) The mass, and b) The charge on the droplet (Assume g = 9.8 m s^{-2})

Solution:- Distance between plates = d = 5.00 mm = 5.00 x 10^{-3} m

Potential difference = V = 780 V

Distance covered by falling particle = S = 1.50 mm = 1.50 x 10^{-3} m

Time taken by particle = t = 11.2 s

Terminal velocity of particle = v_t = S/t = (1.50 x 10^{-3})/11.2 = 1.34 x 10^{-4} m s^{-1}

Density of oil = ρ = 900 kg m^{-3}

Viscosity of air = η = 1.80 x 10^{-5} N m^{-2} s

$r = \sqrt{\frac{9\eta v_t}{2\rho g}} = \sqrt{\frac{9 \, x \, 1.80 \, x \, 10^{-5} x \, 1.33 \, x \, 10^{-4}}{2 \, x \, 900 \, x \, 9.8}} = 1.1 \text{ x } 10^{-6}$ m

a) Mass of particle = m = ρ V = ρ ($\frac{4}{3} \pi r^3$) = $\frac{4}{3}$ (900) (3.14) (1.1 x 10^{-6})^3

<u>m = 5.14 x 10^{-15} kg</u>

b) Charge = q = $^{mgd}/_{V} = \frac{(1.1 \, x \, 10^{-6})(9.8)(1.50 \, x \, 10^{-3})}{780}$

<u>q = 3.20 x 10^{-19} C</u>

Question 12.9:- A proton placed in a uniform electric field of 5000 N C^{-1} directed to right is allowed to go a distance of 10.0 cm from A to B. Calculate (a) Potential difference between the two points (b) Work done by the field (c) The change in P.E. of proton (d) The change in K.E. of the proton (e) Its velocity (mass of proton is 1.67 x 10^{-27} kg)

Solution:- Electric field = E = 5000 N C^{-1}

Distance between A and B = Δr = 10.0 cm = 0.1 m

Charge on proton = q = e = 1.6 x 10^{-19} C

We know that E = - $\frac{\Delta V}{\Delta r}$

(a) Potential difference between A and B = ΔV = - E Δr = - (5000) (0.1)

ΔV = - 500 V

Magnitude of potential difference = |ΔV| = 500 V

(b) Work done by the field = W = q |ΔV| = (1 e) (500 V) = 500 eV

(c) Change in P.E. of proton = ΔP.E. = q ΔV = (1 e) (-500 V) = -500 eV

(d) Change in K.E. of proton = ΔK.E. = W = 500 eV (Work energy principle)

(e) Velocity of proton = v

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

$v = \sqrt{\frac{2 \, K.E.}{m}} = \sqrt{\frac{2 \, (500 \, x \, 1.6 \, x \, 10^{-19})}{(1.67 \, x \, 10^{-27})}} = 3.097 \text{ x } 10^5$ m s^{-1}

Question 12.10:- Using zero reference point at infinity, determine the amount by which a point charge of 4.0 x 10^{-8} C alters the electric potential at a point 1.2 m away, when (a) Charge is positive (b) Charge is negative.

Solution:- Magnitude of charge = q = 4.0 x 10^{-8} C

Distance = r = 1.2 m

(a) Charge is positive

$V = k\frac{q}{r} = (9 \times 10^9)\left(\frac{+4.0 \times 10^{-8}}{1.2}\right) = +300\ V$

V = + 3.0 x 10^2 V

(b) Charge is negative

$V = k\frac{q}{r} = (9 \times 10^9)\left(\frac{-4.0 \times 10^{-8}}{1.2}\right) = -300\ V$

V = - 3.0 x 10^2 V

Question 12.11:- In Bohr's atomic model of hydrogen atom, the electron is in orbit around the nuclear proton at a distance of 5.29 x 10^{-11} m with a speed of 2.18 x 10^6 m s^{-1}. (e = 1.60 x 10^{-19} C, mass of electron = 9.10 x 10^{-31} kg). Find (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.

Solution:- Distance = r = 5.29 x 10^{-11} m

Charge of proton = q = e = 1.60 x 10^{-19} C

Charge of proton = -e = -1.60 x 10^{-19} C

Mass of electron = m = 9.10 x 10^{-31} kg

Speed of electron = v = 2.18 x 10^6 m s^{-1}

(a) Potential exerted by the proton = $V = k\frac{q}{r} = (9 \times 10^9)\left(\frac{1.60 \times 10^{-19}}{5.29 \times 10^{-11}}\right)$

V = +27.20 V

(b) K.E. = $= \frac{1}{2}$ m v^2 = $= \frac{1}{2}$ (9.10 x 10^{-31}) (2.18 x 10^6)^2 = 21.6 x 10^{-19} J

K.E. = $\frac{21.6 \times 10^{-19}}{1.60 \times 10^{-19}}$ eV = 13.60 eV

P.E. = Work done = -e V = (-1 e) (27.20 V)

P.E. = -27.20 eV

Total energy = E = K.E. + P.E. = 13.60 eV + (-27.20 eV)

E = -13.60 eV

(c) The minimum energy required to remove an electron from valence shell of atom is called ionization energy.

Ionization energy = - (Total energy of electron)

E_i = -E = -(-13.60 eV)

<u>$E_i = + 13.60$ eV</u>

Question 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 750 μF capacitor is 330 V. Determine the energy that is sued to produce the flash.

Solution:- Capacitance of the capacitor = C = 750 μF = 750×10^{-6} F

Potential difference between the plate of capacitor = V = 330 V

Energy stored in capacitor = $W = \frac{1}{2} C V^2 = \frac{1}{2} (750 \times 10^{-6}) (330)^2$

<u>**W = 40.8 J**</u>

Question 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? (e = 1.60×10^{-19} C)

Solution:- Capacitance of the capacitor = C = 2.5×10^{-8} F

Potential difference between the plate of capacitor = V = 450 V

Charge on one plate of the capacitor = Q = CV = $(2.5 \times 10^{-8}) (450) = 11.25 \times 10^{-8}$ C

Charge in terms of electrons = Q = ne

We can say that **ne = CV**

$$n = \frac{CV}{e} = \frac{(2.5 \times 10^{-8})\,(450)}{1.60 \times 10^{-19}}$$

<u>**n = 7.0×10^{13} electrons**</u>