Question 1.1:

What is the force between two small charged spheres having charges of 2×10^{-7} C and 3×10^{-7} C placed 30 cm apart in air?

Answer:

Repulsive force of magnitude 6×10^{-3} N

Charge on the first sphere, $q_1 = 2 \times 10^{-7}$ C

Charge on the second sphere, $q_2 = 3 \times 10^{-7}$ C

Distance between the spheres, r = 30 cm = 0.3 m

Electrostatic force between the spheres is given by the relation,

$$F = \frac{q_1 q_2}{4\pi \epsilon_0 r^2}$$

Where, ϵ_0 = Permittivity of free space

$$\frac{1}{4\pi \epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{C}^{-2}$$

$$F = \frac{9 \times 10^9 \times 2 \times 10^{-7} \times 3 \times 10^{-7}}{(0.3)^2} = 6 \times 10^{-3} \text{ N}$$

Hence, force between the two small charged spheres is 6×10^{-3} N. The charges are of same nature. Hence, force between them will be repulsive.

Question 1.2:

The electrostatic force on a small sphere of charge 0.4 μC due to another small sphere of charge − 0.8 μC in air is 0.2 N. (a) What is the distance between the two spheres? (b) What is the force on the second sphere due to the first?

Answer:

(a) Electrostatic force on the first sphere, F = 0.2 N

Charge on this sphere, q_1 = 0.4 μC = 0.4×10^{-6} C

Charge on the second sphere, q_2 = − 0.8 μC = -0.8×10^{-6} C

Electrostatic force between the spheres is given by the relation,

$$F = \frac{q_1 q_2}{4\pi \epsilon_0 r^2}$$

Where, ϵ_0 = Permittivity of free space

$$\text{And, } \frac{1}{4\pi \epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$r^2 = \frac{q_1 q_2}{4\pi \epsilon_0 F}$$

$$= \frac{0.4 \times 10^{-6} \times 8 \times 10^{-6} \times 9 \times 10^9}{0.2}$$

$$= 144 \times 10^{-4}$$

$$r = \sqrt{144 \times 10^{-4}} = 0.12 \text{ m}$$

The distance between the two spheres is 0.12 m.

(b) Both the spheres attract each other with the same force. Therefore, the force on the second sphere due to the first is 0.2 N.

Question 1.3:

Check that the ratio $ke^2/G\, m_e m_p$ is dimensionless. Look up a Table of Physical Constants and determine the value of this ratio. What does the ratio signify?

Answer:

The given ratio is $\frac{ke^2}{Gm_e m_p}$.

Where,

G = Gravitational constant

Its unit is N m^2 kg^{-2}.

m_e and m_p = Masses of electron and proton.

Their unit is kg.

e = Electric charge.

Its unit is C.

k = A constant

$$= \frac{1}{4\pi \in_0}$$

$\in_0$ = Permittivity of free space

Its unit is N m^2 C^{-2}.

Therefore, unit of the given ratio $\frac{ke^2}{Gm_e m_p} = \frac{[\text{Nm}^2\ \text{C}^{-2}][\text{C}^{-2}]}{[\text{Nm}^2\ \text{kg}^{-2}][\text{kg}][\text{kg}]}$

$$= \text{M}^0\text{L}^0\text{T}^0$$

Hence, the given ratio is dimensionless.

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

G = 6.67×10^{-11} N m^2 kg^{-2}

$m_e = 9.1 \times 10^{-31}$ kg

$m_p = 1.66 \times 10^{-27}$ kg

Hence, the numerical value of the given ratio is

$$\frac{ke^2}{Gm_e m_p} = \frac{9\times10^9 \times \left(1.6\times10^{-19}\right)^2}{6.67\times10^{-11}\times9.1\times10^{-3}\times1.67\times10^{-22}} \approx 2.3\times10^{39}$$

This is the ratio of electric force to the gravitational force between a proton and an electron, keeping distance between them constant.

Question 1.4:

(a) Explain the meaning of the statement 'electric charge of a body is quantised'.

(b) Why can one ignore quantisation of electric charge when dealing with macroscopic i.e., large scale charges?

Answer:

(a) Electric charge of a body is quantized. This means that only integral (1, 2, ..., n) number of electrons can be transferred from one body to the other. Charges are not transferred in fraction. Hence, a body possesses total charge only in integral multiples of electric charge.

(b) In macroscopic or large scale charges, the charges used are huge as compared to the magnitude of electric charge. Hence, quantization of electric charge is of no use on macroscopic scale. Therefore, it is ignored and it is considered that electric charge is continuous.

Question 1.5:

When a glass rod is rubbed with a silk cloth, charges appear on both. A similar phenomenon is observed with many other pairs of bodies. Explain how this observation is consistent with the law of conservation of charge.

Answer:

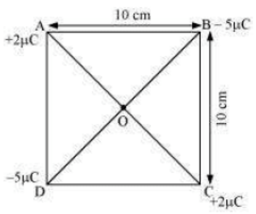
Rubbing produces charges of equal magnitude but of opposite nature on the two bodies because charges are created in pairs. This phenomenon of charging is called charging by friction. The net charge on the system of two rubbed bodies is zero. This is because equal amount of opposite charges annihilate each other. When a glass rod is rubbed with a silk cloth, opposite natured charges appear on both the bodies. This phenomenon is in consistence with the law of conservation of energy. A similar phenomenon is observed with many other pairs of bodies.

Question 1.6:

Four point charges q_A = 2 μC, q_B = −5 μC, q_C = 2 μC, and q_D = −5 μC are located at the corners of a square ABCD of side 10 cm. What is the force on a charge of 1 μC placed at the centre of the square?

Answer:

The given figure shows a square of side 10 cm with four charges placed at its corners. O is the centre of the square.



Where,

(Sides) AB = BC = CD = AD = 10 cm

(Diagonals) AC = BD = $10\sqrt{2}$ cm

AO = OC = DO = OB = $5\sqrt{2}$ cm

A charge of amount 1μC is placed at point O.

Force of repulsion between charges placed at corner A and centre O is equal in magnitude but opposite in direction relative to the force of repulsion between the charges placed at corner C and centre O. Hence, they will cancel each other.

Similarly, force of attraction between charges placed at corner B and centre O is

Similarly, force of attraction between charges placed at corner B and centre O is equal in magnitude but opposite in direction relative to the force of attraction between the charges placed at corner D and centre O. Hence, they will also cancel each other. Therefore, net force caused by the four charges placed at the corner of the square on 1 μC charge at centre O is zero.

Question 1.7:

(a) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?

(b) Explain why two field lines never cross each other at any point?

Answer:

(a) An electrostatic field line is a continuous curve because a charge experiences a continuous force when traced in an electrostatic field. The field line cannot have sudden breaks because the charge moves continuously and does not jump from one point to the other.

(b) If two field lines cross each other at a point, then electric field intensity will show two directions at that point. This is not possible. Hence, two field lines never cross each other.

Question 1.8:

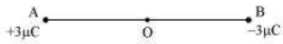
Two point charges q_A = 3 μC and q_B = −3 μC are located 20 cm apart in vacuum.

(a) What is the electric field at the midpoint O of the line AB joining the two charges?

(b) If a negative test charge of magnitude 1.5 × 10^{-9} C is placed at this point, what is the force experienced by the test charge?

Answer:

(a) The situation is represented in the given figure. O is the mid-point of line AB.



Distance between the two charges, AB = 20 cm

∴AO = OB = 10 cm

Net electric field at point O = E

Electric field at point O caused by +3μC charge,

$E_1 = \dfrac{3\times10^{-6}}{4\pi\epsilon_0(\text{AO})^2} = \dfrac{3\times10^{-6}}{4\pi\epsilon_0\left(10\times10^{-2}\right)^2}$ N/C along OB

Where,

ϵ_0 = Permittivity of free space

$\dfrac{1}{4\pi\epsilon_0} = 9\times10^9\ \text{N}\,\text{m}^2\,\text{C}^{-2}$

Magnitude of electric field at point O caused by −3μC charge,

$E_2 = \left|\dfrac{-3\times10^{-6}}{4\pi\epsilon_0(\text{OB})^2}\right| = \dfrac{3\times10^{-6}}{4\pi\epsilon_0\left(10\times10^{-2}\right)^2}$ N/C along OB

$\therefore E = E_1 + E_2$

$= 2\times[\left(9\times10^9\right)\times\dfrac{3\times10^{-6}}{\left(10\times10^{-2}\right)^2}]$ [Since the values of E_1 and E_2 are same, the value is multiplied with 2]

= 5.4 × 10^6 N/C along OB

Therefore, the electric field at mid-point O is 5.4 × 10^6 N C^{-1} along OB.

(b) A test charge of amount 1.5 × 10^{-9} C is placed at mid-point O.

q = 1.5 × 10^{-9} C

Force experienced by the test charge = F

$\therefore F = qE$

= 1.5 × 10^{-9} × 5.4 × 10^6

= 8.1 × 10^{-3} N

The force is directed along line OA. This is because the negative test charge is repelled by the charge placed at point B but attracted towards point A.

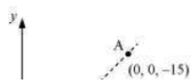
Therefore, the force experienced by the test charge is 8.1 × 10^{-3} N along OA.

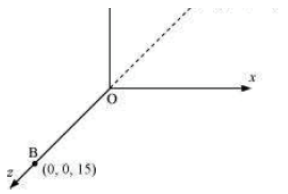
Question 1.9:

A system has two charges q_A = 2.5 × 10^{-7} C and q_B = −2.5 × 10^{-7} C located at points A: (0, 0, − 15 cm) and B: (0, 0, + 15 cm), respectively. What are the total charge and electric dipole moment of the system?

Answer:

Both the charges can be located in a coordinate frame of reference as shown in the given figure.





At A, amount of charge, $q_A = 2.5 \times 10^{-7}$C

At B, amount of charge, $q_B = -2.5 \times 10^{-7}$ C

Total charge of the system,

$q = q_A + q_B$

$= 2.5 \times 10^{7}$ C $- 2.5 \times 10^{-7}$ C

= 0

Distance between two charges at points A and B,

$d = 15 + 15 = 30$ cm = 0.3 m

Electric dipole moment of the system is given by,

$p = q_A \times d = q_B \times d$

$= 2.5 \times 10^{-7} \times 0.3$

$= 7.5 \times 10^{-8}$ C m along positive z-axis

Therefore, the electric dipole moment of the system is 7.5×10^{-8} C m along positive z−axis.

Question 1.10:

An electric dipole with dipole moment 4×10^{-9} C m is aligned at 30° with the direction of a uniform electric field of magnitude 5×10^{4} N C^{-1}. Calculate the magnitude of the torque acting on the dipole.

Answer:

Electric dipole moment, $p = 4 \times 10^{-9}$ C m

Angle made by p with a uniform electric field, $\theta = 30°$

Electric field, $E = 5 \times 10^{4}$ N C^{-1}

Torque acting on the dipole is given by the relation,

$\tau = pE \sin\theta$

$$= 4 \times 10^{-9} \times 5 \times 10^{4} \times \sin 30$$

$$= 20 \times 10^{-5} \times \frac{1}{2}$$

$$= 10^{-4} \text{ N m}$$

Therefore, the magnitude of the torque acting on the dipole is 10^{-4} N m.

Question 1.11:

A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7} C.

(a) Estimate the number of electrons transferred (from which to which?)

(b) Is there a transfer of mass from wool to polythene?

Answer:

(a) When polythene is rubbed against wool, a number of electrons get transferred from wool to polythene. Hence, wool becomes positively charged and polythene becomes negatively charged.

Amount of charge on the polythene piece, $q = -3 \times 10^{-7}$ C

Amount of charge on an electron, $e = -1.6 \times 10^{-19}$ C

Number of electrons transferred from wool to polythene = n

n can be calculated using the relation,

$q = ne$

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

$$= \frac{-3 \times 10^{-7}}{-1.6 \times 10^{-19}}$$

$= 1.87 \times 10^{12}$

Therefore, the number of electrons transferred from wool to polythene is 1.87×10^{12}.

(b) Yes.

There is a transfer of mass taking place. This is because an electron has mass,

$m_e = 9.1 \times 10^{-3}$ kg

Total mass transferred to polythene from wool,

$m = m_e \times n$

$= 9.1 \times 10^{-31} \times 1.85 \times 10^{12}$

$= 1.706 \times 10^{-18}$ kg

Hence, a negligible amount of mass is transferred from wool to polythene.

Question 1.12:

(a) Two insulated charged copper spheres A and B have their centers separated by a distance of 50 cm. What is the mutual force of electrostatic repulsion if the charge on each is 6.5×10^{-7} C? The radii of A and B are negligible compared to the distance of separation.

(b) What is the force of repulsion if each sphere is charged double the above amount, and the distance between them is halved?

Answer:

(a) Charge on sphere A, q_A = Charge on sphere B, $q_B = 6.5 \times 10^{-7}$ C

Distance between the spheres, r = 50 cm = 0.5 m

Force of repulsion between the two spheres,

$$F = \frac{q_A q_B}{4\pi \epsilon_0 r^2}$$

Where,

ϵ_0 = Free space permittivity

$$\frac{1}{4\pi \epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\therefore F = \frac{9\times10^9 \times (6.5\times10^{-7})^2}{(0.5)^2}$$

$= 1.52 \times 10^{-2}$ N

Therefore, the force between the two spheres is 1.52×10^{-2} N.

(b) After doubling the charge, charge on sphere A, q_A = Charge on sphere B, $q_B = 2 \times 6.5 \times 10^{-7}$ C $= 1.3 \times 10^{-6}$ C

The distance between the spheres is halved.

$$\therefore r = \frac{0.5}{2} = 0.25 \text{ m}$$

Force of repulsion between the two spheres,

$$F = \frac{q_A q_B}{4\pi \epsilon_0 r^2}$$

$$= \frac{9\times10^9 \times 1.3\times10^{-6} \times 1.3\times10^{-6}}{(0.25)^2}$$

$= 16 \times 1.52 \times 10^{-2}$

$= 0.243$ N

Therefore, the force between the two spheres is 0.243 N.

Question 1.13:

Suppose the spheres A and B in Exercise 1.12 have identical sizes. A third sphere of the same size but uncharged is brought in contact with the first, then brought in contact with the second, and finally removed from both. What is the new force of repulsion between A and B?

Answer:

Distance between the spheres, A and B, r = 0.5 m

Initially, the charge on each sphere, $q = 6.5 \times 10^{-7}$ C

When sphere A is touched with an uncharged sphere C, $\frac{q}{2}$ amount of charge from A will transfer to sphere C. Hence, charge on each of the spheres, A and C, is $\frac{q}{2}$.

When sphere C with charge $\frac{q}{2}$ is brought in contact with sphere B with charge q, total charges on the system will divide into two equal halves given as,

$$\frac{\frac{q}{2}+q}{2} = \frac{3q}{4}$$

Each sphere will share each half. Hence, charge on each of the spheres, C and B, is $\frac{3q}{4}$.

Force of repulsion between sphere A having charge $\frac{q}{2}$ and sphere B having charge $\frac{3q}{4}$ =

$$\frac{\frac{q}{2}\times\frac{3q}{4}}{4\pi \epsilon_0 r^2} = \frac{3q^2}{8\times4\pi \epsilon_0 r^2}$$

$$= 9\times10^9 \times \frac{3\times(6.5\times10^{-7})^2}{8\times(0.5)^2}$$

$= 5.703 \times 10^{-3}$ N

Therefore, the force of attraction between the two spheres is 5.703×10^{-3} N.

Question 1.14:

Figure 1.33 shows tracks of three charged particles in a uniform electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio?

ratio.

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