Q 1.1 What is the force between two small charged spheres having charges of 2×10^{-7} C and $3 \times 10^{-7} C$ placed 30 cm apart in air?

Answer:

Given,

$q_1 = 2 \times 10^{-7}$ C

$q_2 = 3 \times 10^{-7} C$

r = 30 cm = 0.3 m

We know,

Force between two charged particles, q_1 and q_2 separated by a distance r.

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

$$= \frac{1}{4\pi\epsilon_0}\frac{2 \times 10^{-7} \times 3 \times 10^{-7}}{(30 \times 10^{-2}\ m)^2}$$

$$= (9 \times 10^9\ N) \times \frac{6 \times 10^{-14+4}}{900\ m^2} = 6 \times 10^{-3} N$$

Since the charges are of the same nature, the force is repulsive.

Q 1.2 (a) The electrostatic force on a small sphere of charge $0.4 \mu C$ due to another small sphere of charge $-0.8 \mu C$ in air is $-0.2 N$. (a) What is the distance between the two spheres?

Answer:

Given,

$q_1 = 0.4\mu C$

$q_2 = -0.8\mu C$

F = $-0.2N$ (Attractive)

We know,

Force between two charged particles, q_1 and q_2 separated by a distance r.

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$$

Therefore, the distance between the two charged spheres is 12 cm.

Q 1.2(b) The electrostatic force on a small sphere of charge $0.4\mu C$ due to another small sphere of charge $-0.8\mu C$ in air is $0.2N$.(b)What is the force on the second sphere due to the first?

Answer:

Using Newton's third law, the force exerted by the spheres on each other will be equal in magnitude.

Therefore, the force on the second sphere due to the first = 0.2 N (This force will be attractive since charges are of opposite sign.)

Q 1.3 Check that the ratio $\frac{ke^2}{Gm_em_p}$ is dimensionless. Look up a Table of Physical Constants and determine the value of this ratio. What does the ratio signify?

Answer:

Electrostatic force

$$F = \frac{KQ^2}{r^2}$$

So the dimension of

$[Ke^2] = [Fr^2]$ ....(1)

The gravitational force between two bodies of mass M and m is

$$F = \frac{GMm}{r^2}$$

so dimension of

$[Gm_em_p] = [Fr^2]$ ....(2)

Therefore from (1) and (2)

$[\frac{ke^2}{Gm_em_p}]$ is dimensionless

or

Here,

K = $1/4\pi\epsilon_0$, where ϵ_0 is the permittivity of space. $[1/\epsilon_0] = [C/V.m] = [Nm^2C^{-2}]$

e = Electric charge ([e] = [C])

G = Gravitational constant. ([G]=$[Nm^2kg^{-2}]$)

m_e and m_p are mass of electron and proton ([m_e] = [m_p] = [Kg])

Substituting these units, we get

Hence, this ratio is dimensionless.

Putting the value of the constants

$= 2.3 \times 10^{40}$

The given ratio is the ratio of electric force $\frac{ke^2}{R^2}$ to the gravitational force between an electron and a proton $\frac{Gm_em_p}{R^2}$ considering the distance between them is constant!

Q 1.4 (a) Explain the meaning of the statement 'electric charge of a body is quantised'.

Answer:

The given statement "electric charge of a body is quantised" implies that charge on a body can take only integral values. In other words, only the integral number of electrons can be transferred from one body to another and not in fractions.

Therefore, a charged body can only have an integral multiple of the electric charge of an electron.

Q 1.4 (b) Why can one ignore quantisation of electric charge when dealing with macroscopic i.e., large scale charges?

Answer:

On a macroscopic level, the amount of charge transferred is very large as compared to the charge of a single electron. Therefore, we tend to ignore the quantisation of electric charge in these cases and considered to be continuous in nature.

Q 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:

When a glass rod is rubbed with a silk cloth, opposite charges appear on both the rod and the cloth.

The phenomenon of charging bodies by rubbing them against each other is known as charging by friction. Here, electrons are transferred from one body to another giving both the bodies an equal but opposite charge. The number of electrons lost by one body (attains positive charge due to loss of negatively charged electrons) is equal to the number of electrons gained by the other body (attains negative charge). Therefore, the net charge of the system is zero. This is in accordance with the law of conservation of charge

Q 1.6 Four point charges $q_A = 2\mu C$, $q_B = -5\mu C$, $q_C = 2\mu C$, and $q_D = -5\mu C$ 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:

Charges at (A, C) and (B, D) are pairwise diametrically opposite and also equal.

Therefore, their force on a point charge at the centre of the square will be equal but opposite in directions.

Now, AC = BD = $\sqrt{2} \times (10 \times 10^{-2} m) = \sqrt{2} \times 0.1m$

∴ AO = BO = CO = DO = r = Half of diagonal = $\sqrt{2} \times 0.05m$

Force on point charge at centre due to charges at A and C = $F_A = -F_C = \frac{k(2\mu C)(1\mu C)}{(r)^2}$

Similarly, force on point charge at centre due to charges at B and D = $F_B = -F_D = \frac{k(-5\mu C)(1\mu C)}{(r)^2}$

∴ Net force on point charge = $F_A + F_B + F_C + F_D$

$= -F_B + F_B - F_D + F_D = 0$.

Hence, the charge at the centre experiences no force.

Q 1.7 (a) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?

Answer:

A positive point charge experiences a force in an electrostatic field. Since the charge will experience a continuous force and cannot jump from one point to another, the electric field lines must be continuous.

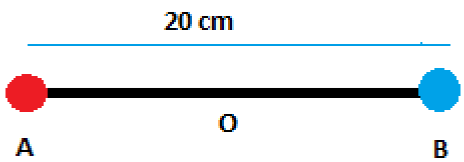
Q 1.7 (b) Explain why two field lines never cross each other at any point?

Answer:

A tangent drawn at any point on a field line gives the direction of force experienced by a unit positive charge due to the electric field on that point. If two lines intersect at a point, then the tangent drawn there will give two directions of force, which is not possible. Hence two field lines cannot cross each other at any point.

Q 1.8 (a) Two point charges $q_A = 3\mu C$ and $q_B = -3\mu C$ 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?

Answer:



Given, AB = 20 cm

Since, O is the midpoint of the line AB.

AO = OB = 10 cm = 0.1m

The electric field at a point caused by charge q, is given as,

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

Where, q is the charge, r is the distance between the charges and the point O

$k = 9 \times 10^{9}\ N\ m^{2}\ C^{-2}$

Now,

Due to charge at A, electric field at O will be E_A and in the direction AO.

$$E_A = \frac{9 \times 10^9 \times 3 \times 10^{-6}}{0.1^2}$$

Similarly the electric field at O due to charge at B, also in the direction AO

$$E_B = \frac{9 \times 10^9 \times (-3 \times 10^{-6})}{0.1^2}$$

Since, both the forces are acting in the same direction, we can add their magnitudes to get the net electric field at O:

E' = E_A + E_B = 2E (Since their magnitudes are same)

$$E' = 2 \times \frac{9 \times 10^9 \times 3 \times 10^{-6}}{0.1^2} = 5.4 \times 10^4 N/C$$ along the direction AO.

Q 1.8 (b) Two point charges $q_A = 3\mu C$ and $q_B = -3\mu C$ are located 20 cm apart in vacuum. If a negative test charge of magnitude $1.5 \times 10^{-9} C$ is placed at this point, what is the force experienced by the test charge?

Answer:

Let Q = -1.5×10^{-9} C

The force experienced by Q when placed at O due to the charges at A and B will be:

$$F = Q \times E'$$

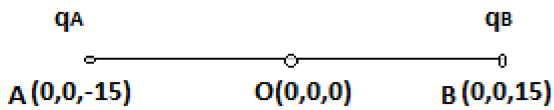
where 'E' is the net electric field at point O.

$$F = 1.5 \times 10^{-9} C \times 5.4 \times 10^4 N/C = 8.1 \times 10^{-3} N$$

Q being negatively charged will be attracted by positive charge at A and repelled by negative charge at B. Hence the direction of force experienced by it will be in the direction of OA.

Q 1.9 A system has two charges $q_A = 2.5 \times 10^{-7} C$ and $q_B = -2.5 \times 10^{-7}$ 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:



Given,

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

The total charge of the system = $q_A + q_B = 0$

$\therefore$ The system is electrically neutral. (All dipole systems have net charge zero!)

Now, distance between the two charges, d = 15 + 15 = 30 cm = 0.3 m

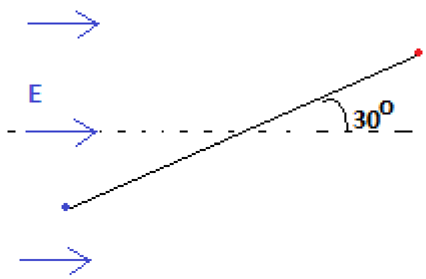
We know, The electric dipole moment of the system, p = q_A x d = q_B x d (i.e, the magnitude of charge x distance between the two charges)

$\therefore p = 2.5 \times 10^{-7} C \times 0.3 m = 7.5 \times 10^{-8} Cm$

The direction of a dipole is towards the positive charge . Hence, in the positive z-direction.

Q 1.10 An electric dipole with dipole moment $4 \times 10^{-9} Cm$ is aligned at 30° with the direction of a uniform electric field of magnitude $5 \times 10^{4} NC^{-1}$. Calculate the magnitude of the torque acting on the dipole.

Answer:



Given,

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

$\Theta = 30^0 \;\therefore\; sin\Theta = 0.5$

E = $5 \times 10^4 NC^{-1}$

We know, the torque acting on a dipole is given by:

$\tau = p \times E$

$\implies \tau = pEsin\Theta = 4 \times 10^{-9} \times 5 \times 10^4 \times 0.5 \ Nm$

$\implies \tau = 10^{-4} Nm$

Therefore, the magnitude of torque acting on the dipole is $10^{-4} Nm$

Q 1.11 (a) A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7}.

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

Answer:

Clearly, polyethene being negatively charged implies that it has an excess of electrons(which are negatively charged!). Therefore, electrons were transferred from wool to polyethene.

Given, charge attained by polyethene = -3×10^{-7} C

We know, Charge on 1 electron = $-1.6 \times 10^{-19} C$

Therefore, the number of electrons transferred to attain a charge of -3×10^{-7} =

$\frac{-3 \times 10^{-7}}{-1.6 \times 10^{-19} C} = 1.8 \times 10^{12}$ electrons.

Q 1.11 (b) A polythene piece rubbed with wool is found to have a negative charge of $3 \times 10^{-7} C$. Is there a transfer of mass from wool to polythene?

Answer:

The charge attained by polyethene (and also wool!) is solely due to the transfer of free electrons.

We know, Mass of an electron = $9.1 \times 10^{-31}\ kg$

The total mass of electron transferred = number of electrons transferred x mass of an electron

= $9.1 \times 10^{-31} \times 1.8 \times 10^{12}\ kg = 16.4 \times 10^{-19}\ kg$

Yes, there is a transfer of mass but negligible.

Q 1.12 (a) Two insulated charged copper spheres A and B have their centres separated by a distance of 50 cm. What is the mutual force of electrostatic repulsion if the charge on each is $6.5 \times 10^{-7} C$? The radii of A and B are negligible compared to the distance of separation.

Answer:

Since the radii of the spheres A and B are negligible compared to the distance of separation, we consider them as a point object.

Given,

charge on each of the spheres = $6.5 \times 10^{-7} C$

and distance between them, r = 50 cm = 0.5 m

We know,

$$F = k\frac{q_1 q_2}{r^2}$$

Therefore, the mutual force of electrostatic repulsion(since they have the same sign of charge)

$$F = 9 \times 10^9 Nm^2C^{-2} \times \frac{(6.5 \times 10^{-7}\ C)^2}{(0.5\ m)^2} = 1.5 \times 10^{-2} N$$

Q 1.12 (b) What is the force of repulsion if each sphere is charged double the above amount, and the distance between them is halved?

Answer:

We know, force between two charged particles separated by a distance r is:

$$F = k\frac{q_1 q_2}{r^2} = k\frac{q^2}{r^2} (\because q_1 = q_2 = q)$$

Now if $q \to 2q\ and\ r \to r/2$

The new value of force:

$$F_{new} = k\frac{(2q)^2}{(r/2)^2} = 16k\frac{q^2}{r^2} = 16F$$

Therefore, the force increases 16 times!

$F_{new} = 16F = 16 \times 1.5 \times 10^{-2} N = 0.24\ N$

Q 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:

When two spheres of the same size are touched, on attaining the equipotential state, the total charge of the system is equally distributed on both of them.

Therefore, (i) When uncharged third sphere C is touched with A, charge left on A $= 0.5 \times 6.5 \times 10^{-7} C$

and charge attained by C $= 0.5 \times 6.5 \times 10^{-7} C$

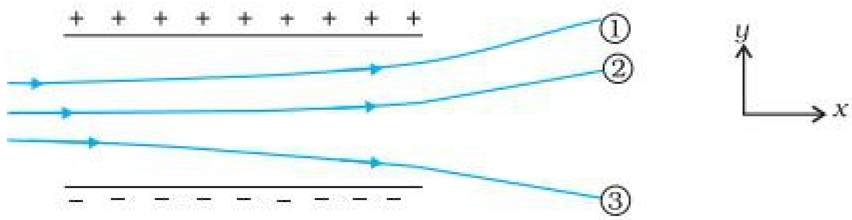
(ii) Now, charge on B + charge on C $= 6.5 \times 10^{-7} C + 0.5 \times 6.5 \times 10^{-7} C = 1.5 \times 6.5 \times 10^{-7} C$

When touched, charge left on B $= 0.5 \times 1.5 \times 6.5 \times 10^{-7} C$

Therefore $q_A \rightarrow 0.5 \times q_A\ and\ q_B \rightarrow 0.75 \times q_B$

Therefore, $F' = 0.5 \times 0.75 \times F = 0.375 \times 1.5 \times 10^{-2} N = \mathbf{5.7 \times 10^{-3}\ N}$

Q 1.14 Figure 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?



Answer:

Charges 1 and 2 are repelled by the negatively charged plate of the system

Hence 1 and 2 are negatively charged .

Similarly, 3 being repelled by positive plate is positively charged.

(charge to the mass ratio: charge per unit mass)

Since 3 is deflected the most, it has the highest charge to mass ratio .

Q 1.15 (a) Consider a uniform electric field $E = 3 \times 10^3 \, \hat{i} \, N/C$. (a) What is the flux of this field through a square of 10 cm on a side whose plane is parallel to the yz plane?

Answer:

Given,

$$E = 3 \times 10^3 \, \hat{i} \, \frac{N}{C}$$

Area of the square = $0.01^2 \; m^2$

Since the square is parallel to the yz plane, therefore it's normal is in x-direction.(i.e $\hat{i}$ direction)

therefore, flux through this surface:

$\phi = E.A$

$\implies \phi = (3 \times 10^3 \,\hat{i}).(0.01\,\hat{i}) Nm^2/C = \mathbf{30 Nm^2/C}$

Q 1.15 (b) Consider a uniform electric field $E = 3 \times 10^3 \,\hat{i}\, N/C$ .What is the flux through the same square if the normal to its plane makes a 60° angle with the x-axis?

Answer:

Now, Since the normal of the square plane makes a 60° angle with the x-axis

$cos\Theta = cos(60^0) = 0.5$

therefore, flux through this surface:

$\phi = E.A = EAcos\Theta$

$\implies \phi = (3 \times 10^3)(0.01)(0.5) Nm^2/C = \mathbf{15 \ Nm^2/C}$

Q 1.16 What is the net flux of the uniform electric field of Exercise 1.15 through a cube of side 20 cm oriented so that its faces are parallel to the coordinate planes?

Answer:

The net flux of the uniform electric field through a cube oriented so that its faces are parallel to the coordinate planes is z ero .

This is because the number of lines entering the cube is the same as the number of lines leaving the cube.

Alternatively,

using Gauss's law, we know that the flux of electric field through any closed surface S is $1/\epsilon_0$ times the total charge enclosed by S.

i.e. $\phi = q/\epsilon_0$

where, q = net charge enclosed and ϵ_0 = permittivity of free space (constant)

Since there is no charge enclosed in the cube, hence $\phi = 0$.

Q 1.17 (a) Careful measurement of the electric field at the surface of a black box indicates that the net outward flux through the surface of the box is $8.0 \times 10^3 \frac{Nm^2}{C}$. (a) What is the net charge inside the box?

Answer:

Using Gauss's law, we know that the flux of electric field through any closed surface S is $1/\epsilon_0$ times the total charge enclosed by S.

i.e. $\phi = q/\epsilon_0$

where, q = net charge enclosed and ϵ_0 = permittivity of free space (constant)

Given, $\phi = 8.0 \times 10^3 \ Nm^2/C$

$\therefore q = \phi \times \epsilon_0 = (8.0 \times 10^3 \times 8.85 \times 10^{-12}) \ C$

$\implies \ q = 70 \times 10^{-9} C = \mathbf{0.07 \mu C}$

This is the net charge inside the box.

Q 1.17 (b) Careful measurement of the electric field at the surface of a black box indicates that the net outward flux through the surface of the box is $8.0 \times 10^3 \frac{Nm^2}{C}$ .If the net outward flux through the surface of the box were zero, could you conclude that there were no charges inside the box? Why or Why not?

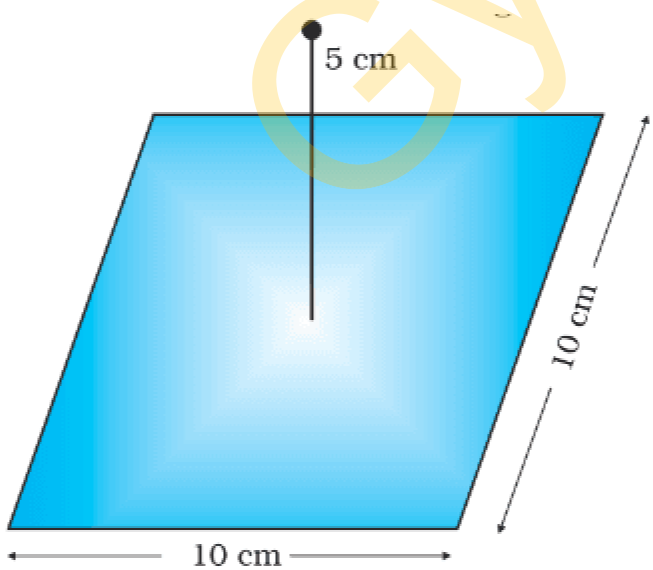
Answer:

Using Gauss's law, we know that $\phi = q/\epsilon_0$

Since flux is zero, q = 0, but this q is the net charge enclosed by the surface.

Hence, we can conclusively say that net charge is zero, but we cannot conclude that there are no charges inside the box.

Q 1.18 A point charge $+10\mu C$ is a distance 5 cm directly above the centre of a square of side 10 cm, as shown in Fig. What is the magnitude of the electric flux through the square? (Hint: Think of the square as one face of a cube with edge 10 cm.)



Answer:

Let us assume that the charge is at the centre of the cube with edge 10 cm.

Using Gauss's law, we know that the flux of electric field through any closed surface S is $1/\epsilon_0$ times the total charge enclosed by S.

i.e. $\phi = q/\epsilon_0$

where, q = net charge enclosed and ϵ_0 = permittivity of free space (constant)

Therefore, flux through the cube: $\phi = (10 \times 10^{-6} C)/\epsilon_0$

Due to symmetry, we can conclude that the flux through each side of the cube, ϕ' , will be equal.

Q 1.19 A point charge of $2.0 \mu C$ is at the centre of a cubic Gaussian surface 9.0 cm on edge. What is the net electric flux through the surface?

Answer:

Given,

q = net charge inside the cube = $2.0 \mu C$

Using Gauss's law, we know that the flux of electric field through any closed surface S is $1/\epsilon_0$ times the total charge enclosed by S.

i.e. $\phi = q/\epsilon_0$

where, q = net charge enclosed and ϵ_0 = permittivity of free space (constant)

$\therefore \phi = 2.0 \times 10^{-6}/8.85 \times 10^{-12}\ Nm^2C^{-1} = \mathbf{2.2 \times 10^5\ Nm^2C^{-1}}$

(Note: Using Gauss's formula, we see that the electric flux through the cube is independent of the position of the charge and dimension of the cube!)

Q 1.20 (a)A point charge causes an electric flux of $-1.0 \times 10^3 \frac{Nm^2}{C}$ to pass through a spherical Gaussian surface of 10.0 cm radius centred on the charge. If the radius of the Gaussian surface were doubled, how much flux would pass through the surface?

Answer:

Given,

$$\phi = -1.0 \times 10^3 \frac{Nm^2}{C}$$

Using Gauss's law, we know that the flux of electric field through any closed surface S is $1/\epsilon_0$ times the total charge enclosed by S.

i.e. $\phi = q/\epsilon_0$

where, q = net charge enclosed and ϵ_0 = permittivity of free space (constant)

Therefore, flux does not depend on the radius of the sphere but only on the net charge enclosed. Hence, the flux remains the same although the radius is doubled.

$$\phi' = -10^3 \frac{Nm^2}{C}$$

Q 1.20 (b) A point charge causes an electric flux of $-1.0 \times 10^3 \frac{Nm^2}{C}$ to pass through a spherical Gaussian surface of 10.0 cm radius centred on the charge. What is the value of the point charge?

Answer:

Given,

$$\phi = -1.0 \times 10^3 \frac{Nm^2}{C}$$

Using Gauss's law, we know that the flux of electric field through any closed surface S is $1/\epsilon_0$ times the total charge enclosed by S.

i.e. $\phi = q/\epsilon_0$

where, q = net charge enclosed and ϵ_0 = permittivity of free space (constant)

Q 1.21 A conducting sphere of radius 10 cm has an unknown charge. If the electric field 20 cm from the centre of the sphere is $1.5 \times 10^3 \frac{N}{C}$ and points radially inward, what is the net charge on the sphere?

Answer:

We know, for determining the electric field at r>R for a conducting sphere, the sphere can be considered as a point charge located at its centre.

Also, electric field intensity at a point P, located at a distance r, due to net charge q is given by,

$$E = k\frac{q}{r^2}$$

Given, r = 20 cm = 0.2 m (From the centre, not from the surface!)

Therefore, charge on the conducting sphere is $-6.67\ nC$ (since flux is inwards)

Q 1.22 (a) A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of $80.0\frac{\mu C}{m^2}$. (a) Find the charge on the sphere.

Answer:

Given,

Surface charge density = $80.0\mu C m^{-2}$

Diameter of sphere = 2.4 m ∴ radius of sphere, r = 1.2 m

The charge on the sphere, Q= surface charge density x surface area of the sphere

$= (80 \times 10^{-6}) \times (4\pi r^2) = 320 \times 22/7 \times (1.2)^2 = \mathbf{1.45 \times 10^{-3}}\ \boldsymbol{C}$

Q 1.22 (b) A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of $80.0\frac{\mu C}{m^2}$. (b) What is the total electric flux leaving the surface of the sphere?

Answer:

Using Gauss's law, we know that :

$\phi = q/\epsilon_0$

$\implies \phi = 1.45 \times 10^{-3}/8.85 \times 10^{-12} = 1.6 \times 10^8\ Nm^2C^{-1}$

Q 1.23 An infinite line charge produces a field of $9 \times 10^4 \frac{N}{C}$ at a distance of 2 cm. Calculate the linear charge density.

Answer:

Given,

$\lambda = 9 \times 10^4 \frac{N}{C}$

d = 2 cm = 0.02 m

We know, For an infinite line charge having linear charge density λ, the electric field at a distance d is:

$E = k\lambda/d$

$\therefore 9 \times 10^4 = 9 \times 10^9 \lambda/0.02$

ï¿¼

The linear charge density is $10\mu C/cm$.

Q 1.24 (a) Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude $17 \times 10^{-22} \frac{C}{m^2}$ What is E: (a) in the outer region of the first plate

Answer:

We know, electric field, E, due to an infinite plate (length>>thickness) having surface charge density $\sigma = \sigma/2\epsilon_0$.

(To note: It's independent of distance from the plate!)

In the region outside the first plate,

since both plates have the same surface charge density(in magnitude only), their electric fields are same in magnitude in this region but opposite in direction.

(E due to positive plate away from it and E due to negative plate towards it!)

Hence, the electric field in the outer region of the first plate is zero.

Q 1.24 (b) Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude $17 \times 10^{-22} \frac{C}{m^2}$. What is E:(b) in the outer region of the second plate

Answer:

We know, electric field, E, due to an infinite plate (length>>thickness) having surface charge density $\sigma = \sigma/2\epsilon_0$.

(To note: It's independent of distance from the plate and same everywhere!)

In the region outside the second plate,

Since both plates have the same surface charge density(in magnitude only), their electric fields are same in magnitude in this region but opposite in direction.

(E due to positive plate away from it and E due to negative plate towards it!)

Hence, the electric field in the outer region of the second plate is zero.

Q 1.24 (c) Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude $17 \times 10^{-22} \frac{C}{m^2}$. What is E:(c) between the plates?

Answer:

We know, electric field, E, due to an infinite plate (length>>thickness) having surface charge density $\sigma = \sigma/\epsilon_0$.

(To note: It's independent of distance from the plate!)

Let A and B be the two plates such that:

$\sigma_A = 17 \times 10^{-22} Cm^{-2} = \sigma$

$\sigma_B = -17 \times 10^{-22} Cm^{-2} = -\sigma$

Therefore,

The electric field between the plates, E = $E_A + E_B = \sigma_A/2\epsilon_0 + (-\sigma_B/2\epsilon_0)$

$= \sigma/2\epsilon_0 = 17 \times 10^{-22}/8.85 \times 10^{-12} = 1.92 \times 10^{-10} NC^{-1}$

NCERT solutions for class 12 physics chapter 1 electric charges and fields additional exercises

Q 1.25 An oil drop of 12 excess electrons is held stationary under a constant electric field of $2.55 \times 10^4 NC^{-1}$(Millikan's oil drop experiment). The density of the oil is 1.26 g cm^{-3} . Estimate the radius of the drop.

Answer:

The force due to the electric field is balancing the weight of the oil droplet.

weight of the oil drop = density x volume of the droplet x g = $\rho \times \frac{4}{3}\pi r^3 \times g$

Force due to the electric field = E x q

charge on the droplet, q = No. of excess electrons x charge of an electron

$= 12 \times q_e = 12 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-18} C$

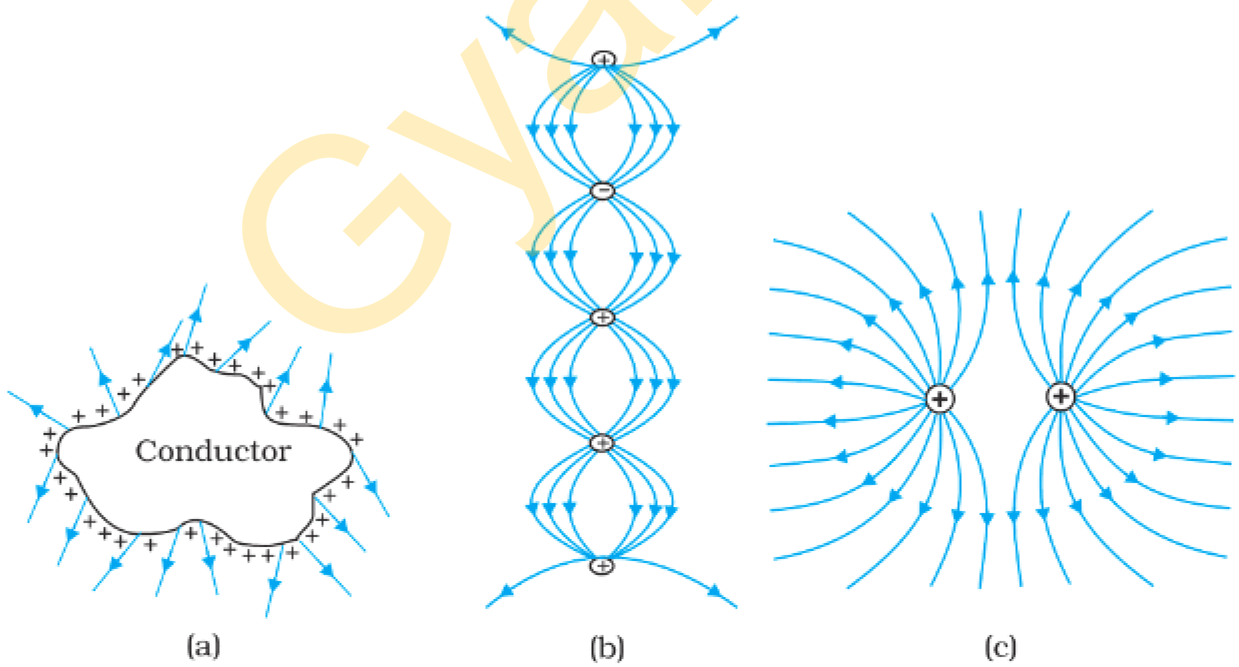
Balancing forces:

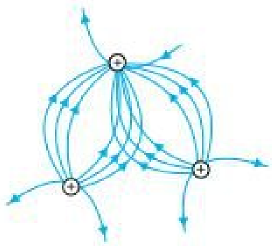
$$\rho \times \frac{4}{3}\pi r^3 \times g = E \times q$$

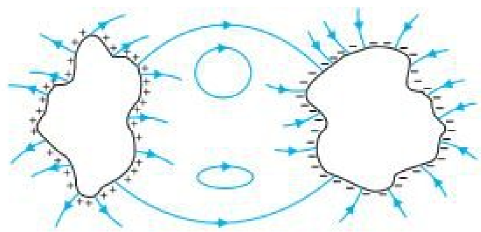
Putting known and calculated values:

$$r = 0.975 \times 10^{-6} m = 9.75 \times 10^{-4} mm$$

Q 1.26 Which among the curves shown in Figure cannot possibly represent electrostatic field lines?




(d)


(e)

Answer:

(a) Wrong, because field lines must be normal to a conductor.

(b) Wrong, because field lines can only start from a positive charge. It cannot start from a negative charge,

(c) Right;

(d) Wrong, because field lines cannot intersect each other,

(e) Wrong, because electrostatic field lines cannot form closed loops.

Q 1.27 In a certain region of space, electric field is along the z-direction throughout. The magnitude of electric field is, however, not constant but increases uniformly along the positive z-direction, at the rate of $10^5 NC^{-1}$ per metre. What are the force and torque experienced by a system having a total dipole moment equal to 10^{-7} Cm in the negative z-direction ?

Answer:

Force on a charge F=qE

but here E is varying along the Z direction.

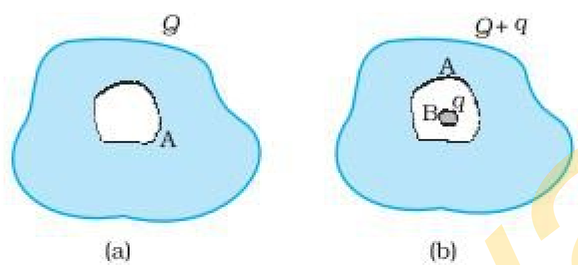
Force can be written as,

$$F = q\frac{dE}{dz}dz = P\frac{dE}{dz} = 10^{-7} \times 10^{5} = 10^{-2}N$$

Torque experienced =0 since both dipole and electric field are in the Z direction. The angle between dipole and the electric field is 180 degrees

$$\tau = \mathbf{P} \times \mathbf{E} = PEsin\ 180 = 0$$

Q 1.28 (a) A conductor A with a cavity as shown in Figure a is given a charge Q. Show that the entire charge must appear on the outer surface of the conductor.



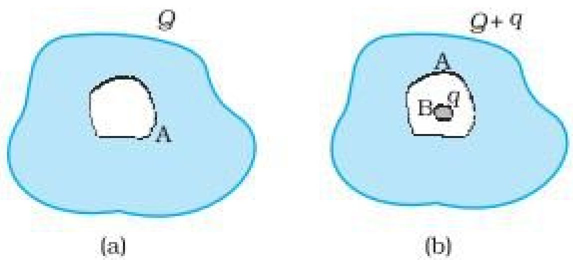
Answer:

We know that the electric field inside a conductor is zero.

Using Gauss' law, if we draw any imaginary closed surface inside the solid, net charge must be zero.(Since E= 0 inside)

Hence there cannot be any charge inside the conductor and therefore, all charge must appear on the outer surface of the conductor.

Q 1.28 (b) Another conductor B with charge q is inserted into the cavity keeping B insulated from A. Show that the total charge on the outside surface of A is Q + q



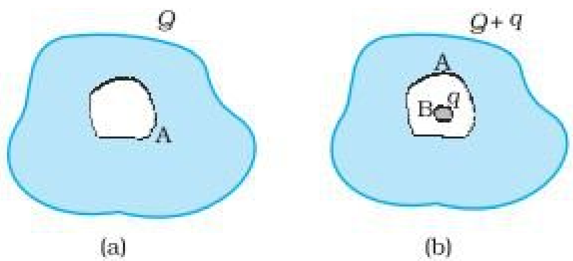
Answer:

We know, electric field inside a conductor is zero.

Now, imagine a Gaussian surface just outside the cavity inside the conductor. Since, E=0 (Using Gauss' law), hence net charge must be zero inside the surface. Therefore, -q charge is induced on the inner side of the cavity(facing conductor B).

Now consider a Gaussian surface just outside the conductor A. The net electric field must be due to charge Q and q. Hence, q charge is induced on the outer surface of conductor A. Therefore, the net charge on the outer surface of A is Q + q.

Q 1.28 (c) A sensitive instrument is to be shielded from the strong electrostatic fields in its environment. Suggest a possible way.



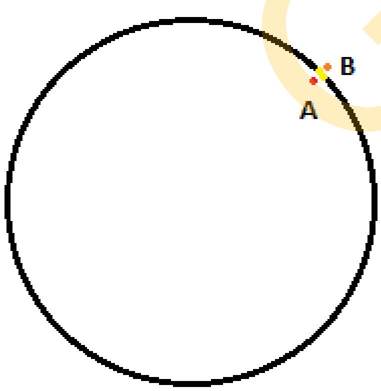
Answer:

We know that the electric field inside a conductor is zero.

Therefore, a possible way to shield from the strong electrostatic fields in its environment is to enclose the instrument fully by a metallic surface.

Q 1.29 A hollow charged conductor has a tiny hole cut into its surface. Show that the electric field in the hole is $\left(\frac{\sigma}{2\epsilon_0}\right)\hat{n}$, where $\hat{n}$ is the unit vector in the outward normal direction, and σ is the surface charge density near the hole.

Answer:



Let the surface area of the sphere be S.

And assume that the hole is filled. For a point B, just above the hole, considering a gaussian surface passing through B, we have

$$\oint E.dS = q/\epsilon_0$$

Now, since the electric field is always perpendicular to the surface of the conductor.

$$\therefore \oint E.dS = E.S = q/\epsilon_0 = (\sigma.S)/\epsilon_0$$
$$\implies E = \sigma/\epsilon_0$$

Using Superposition principle, $E = E_1 + E_2$,

where E_1 is due to the hole and E_2 is due to the rest of the conductor. (both pointing outwards, i.e away from the centre)

Again, for a point A, just below the hole, Electric field will be zero because of electrostatic shielding.

Using the superposition principle, this will be due to E_1 pointing inwards(towards the centre) and due to E_2 (Pointing away from the centre)

$$0 = E_1 - E_2 \implies E_1 = E_2$$

Using this relation, we get:

$$E = E_1 + E_2 = 2E_1 \implies E_1 = E/2 = \sigma/2\epsilon_0$$

Since this is pointing outwards,

$\boldsymbol{E_1} = \sigma/2\epsilon_0 \, \boldsymbol{\hat{n}}$ is the electric field in the hole.

(Trick: 1. Assume the hole to be filled.

2. Consider 2 points just above and below the hole.

3. Electric fields at these points will be due to the hole and rest of the conductor. Use superposition principle.)

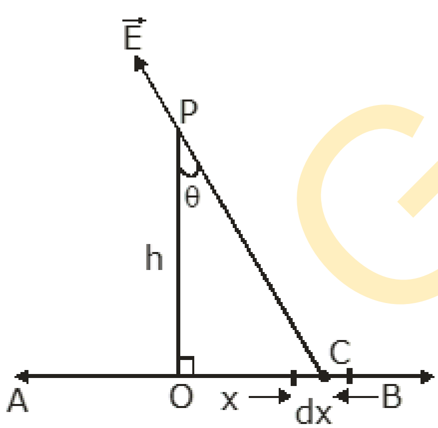
Q 1.30 Obtain the formula for the electric field due to a long thin wire of uniform linear charge density E without using Gauss's law.

[Hint: Use Coulomb's law directly and evaluate the necessary integral.]

Answer:

Let AB be a long thin wire of uniform linear charge density λ.

Let us consider the electric field intensity due to AB at point P at a distance h from it as shown in the figure.



The charge on a small length dx on the line AB is q which is given as q = λdx.

So, according to Coulomb's law, the electric field at P due to this length dx is

$$dE' = \frac{1}{4\pi\epsilon}\frac{\lambda dx}{(PC)^2}$$

But $PC = \sqrt{h^2 + x^2}$

$\Rightarrow dE = \frac{1}{4\pi\epsilon}\frac{\lambda dx}{(h^2 + x^2)}$

This electric field at P can be resolved into two components as dEcosθ and dEsinθ. When the entire length AB is considered, then the dEsinθ components add up to zero due to symmetry. Hence, there is only dEcosθ component.

So, the net electric field at P due to dx is

dE' = dE cosθ

$\Rightarrow dE' = \frac{\lambda dx \cos\theta}{4\pi\epsilon(h^2 + x^2)}$ ……………………(1)

In ΔPOC,

$\tan\theta = \frac{x}{h}$

$\Rightarrow x = h \tan\theta$

Differentiating both sides w.r.t. θ,

$\frac{dx}{d\theta} = h \sec^2\theta$

$\Rightarrow dx = h \sec^2\theta \, d\theta$ ……………………….(2)

Also, $h^2 + x^2 = h^2 + h^2 \tan^2\theta$

$\Rightarrow h^2 + x^2 = h^2 (1 + \tan^2\theta)$

$\Rightarrow h^2 + x^2 = h^2 \sec^2 \theta$ …………(3)

(Using the trigonometric identity, $1 + \tan^2 \theta = \sec^2 \theta$)

Using equations (2) and (3) in equation (1),

$$dE' = \frac{\lambda \cos \theta \times h \sec^2 \theta}{4\pi\epsilon \times h^2 \sec^2 \theta} d\theta$$

$$dE' = \frac{\lambda \cos \theta}{4\pi\epsilon h} d\theta$$

,

The wire extends from $\theta = -\frac{\pi}{2}$ to $\theta = \frac{\pi}{2}$ since it is very long.

Integrating both sides,

$$E' = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{\lambda \cos \theta}{4\pi\epsilon h} d\theta$$

$$E' = \frac{\lambda}{4\pi\epsilon h} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos \theta \, d\theta$$

$$E' = \frac{\lambda}{4\pi\epsilon h} \left(\sin\frac{\pi}{2} - \sin\left(-\frac{\pi}{2}\right)\right)$$

$$E' = \frac{\lambda}{4\pi\epsilon h} \times 2$$

$$E' = \frac{\lambda}{2\pi\epsilon h}$$

This is the net electric field due to a long wire with linear charge density λ at a distance h from it.

In the question linear charge density =E

therefor

$$E' = \frac{E}{2\pi\epsilon h}$$

Q 1.31 It is now believed that protons and neutrons (which constitute nuclei of ordinary matter) are themselves built out of more elementary units called quarks. A proton and a neutron consist of three quarks each. Two types of quarks, the so called 'up' quark (denoted by u) of charge + $\left(\frac{2}{3}\right)$ e, and the 'down' quark (denoted by d) of charge $\left(-\frac{1}{3}\right)$ e, together with electrons build up ordinary matter. (Quarks of other types have also been found which give rise to different unusual varieties of matter.) Suggest a possible quark composition of a proton and neutron.

Answer:

Given, a proton and a neutron consist of three quarks each.

And, 'up' quark is of charge + $\left(\frac{2}{3}\right)$ e, and the 'down' quark of charge $\left(-\frac{1}{3}\right)$ e

Let the number of 'up' quarks be n. Therefore, the number of 'down' quarks is (3-n).

$\therefore$ The net charge = $n \times \frac{2}{3}e + (3-n)\frac{-1}{3}e = (n-1)e$

Now, a proton has a charge +1e

$\therefore (n-1)e = +1e \implies n = 2$

Proton will have 2 u and 1 d, i.e, uud

Similarly, the neutron has a charge 0

$\therefore (n-1)e = 0 \implies n = 1$

Neutron will have 1 u and 2 d, i.e, udd

Q 1.32 (a) Consider an arbitrary electrostatic field configuration. A small test charge is placed at a null point (i.e., where E = 0) of the configuration. Show that the equilibrium of the test charge is necessarily unstable.

Answer:

For equilibrium to be stable, there must be a restoring force and hence all the field lines should be directed inwards towards the null point. This implies that there is a net inward flux of the electric field. But this violates Gauss's law, which states that the flux of electric field through a surface not enclosing any charge must be zero. Hence, the equilibrium of the test charge cannot be stable.

Therefore, the equilibrium is necessarily unstable.

Q 1.32 (b) Verify this result for the simple configuration of two charges of the same magnitude and sign placed a certain distance apart.

Answer:

Two charges of same magnitude and sign are placed at a certain distance apart. The mid-point of the line joining these charges will have E =0.

When a test charged is displaced along the line towards the charges, it experiences a restoring force(which is the condition for stable equilibrium). But if the test charge is displaced along the normal of the line, the net electrostatic force pushes it away from the starting point. Hence, the equilibrium is unstable.

Q 1.33 A particle of mass m and charge (–q) enters the region between the two charged plates initially moving along x-axis with speed vx .The length of plate is L and an uniform electric field

E is maintained between the plates. Show that the vertical deflection of the particle at the far edge of the plate is $\frac{qEL^2}{2mv_x^2}$.

Answer:

Let s be the vertical deflection, t be the time taken by the particle to travel between the plates

$\therefore s = ut + \frac{1}{2}at^2$

Here , u =0 , since initially there was no vertical component of velocity.

The particle in the elecric field will experience a constant force (Since, Electric field is constant.)

F = ma = -qE (Using Newton's Second Law, F = ma)

∴ a = -qE/m (-ve sign implies here in downward direction)

Again, t = Distance covered/ Speed = L/v_x

(In x-direction, since there is no force, hence component of velocity in x-direction remains constant = v_x.

And, the distance covered in x-direction = length of the plate = L)

Putting these values in our deflection equation,

(S is -ve, which implies it deflect in downwards direction.)

∴ The vertical deflection of the particle at the far edge of the plate is $\frac{qEL^2}{2mv_x^2}$.

This motion is similar to the motion of a projectile in a gravitational field, which is also a constant force. The force acting on the particle in the gravitational field is mg whiles in this case, it is qE. The trajectory will be the same in both cases.

Q 1.34 Suppose that the particle in is an electron projected with velocity $v_x = 2.0 \times 10^6 ms^{-1}$. If E between the plates separated by 0.5 cm is $9.1 \times 10^2 \frac{N}{C}$, where will the electron strike the upper plate?
(|e|= $|e| = 1.6 \times 10^{-19}, m_e = 9.1 \times 10^{-31} kg$)

Answer:

∴ The vertical deflection of the particle at the far edge of the plate is $s = \frac{qEL^2}{2mv_x^2}$

given s= 0.5cm=0.005cm

calculate for L from the above equation

L=1.6 cm