



# NCERT Solutions for 12th Class Physics: Chapter 1-Electric Charges And Fields



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## NCERT Solutions for 12th Class Physics: Chapter 1-Electric Charges And Fields

Class 12: Physics Chapter 1 solutions. Complete Class 12 Physics Chapter 1 Notes.

### NCERT Solutions for 12th Class Physics: Chapter 1-Electric Charges And Fields

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#### Question 1.

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

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**Solution:**

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} = 9 \times 10^9 \times \frac{2 \times 10^{-7} \times 3 \times 10^{-7}}{(30 \times 10^{-2})^2}$$

or  $F = 6 \times 10^{-3}$  N (repulsive in nature, as the two charges are like charges.)

**Question 2.**

The electrostatic force on a small sphere of charge  $0.4 \mu\text{C}$  due to another small sphere of charge  $-0.8 \mu\text{C}$  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?

**Solution:**

(a) Given,  $F_{12} = 0.2$  N,  $q_1 = 0.4 \times 10^{-6}$  C,  
 $q_2 = -0.8 \times 10^{-6}$  C

$$\text{As, } F_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$\text{or } r^2 = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{F_{12}}$$

$$= 9 \times 10^9 \times \frac{0.4 \times 10^{-6} \times 0.8 \times 10^{-6}}{0.2}$$

$$\text{or } r^2 = 14.4 \times 10^{-3} = 1.44 \times 10^{-2}$$

$$\text{or } r = 1.2 \times 10^{-1} \text{ m} = 12 \text{ cm}$$

(b) By Newton's third law,  $F_{21} = F_{12} = 0.2$  N  
attractive

**Question 3.**

Check that the ratio

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$$\frac{Ke^2}{Gm_em_p}$$

is dimensionless. Look up a table of Physical Constants and determine the value of this ratio. What does the ratio signify?

**Solution:**

The ratio of electrostatic force to the gravitational force between an electron and a proton separated by a distance  $r$  from each other is

This ratio signifies that electrostatic forces are  $10^{39}$  times stronger than gravitational forces.

**Question 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?

**Solution:**

(a) The net charge possessed by a body is an integral multiple of charge of an electron i.e.  $q = \pm ne$ , where  $n = 0, 1, 2, 3, \dots$  is the number of electrons lost/gained by the body and  $e = 1.6 \times 10^{-19}$  C is charge of an electron. This is called law of quantization of charge.

(b) At macroscopic level, charges are enormously large as compared to the charge of an electron,  $e = 1.6 \times 10^{-19}$  C. Even a charge of 1 nC contains nearly  $10^{13}$  electronic charges. So, at this large scale, charge can have a continuous value rather than discrete integral multiple of  $e$ , and hence, the quantization of electric charge can be ignored.

**Question 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.

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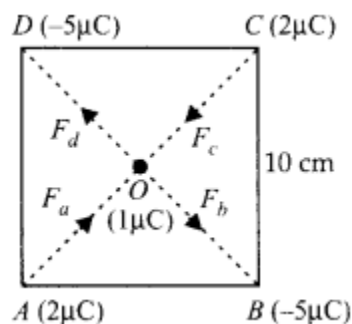
**Solution:**

When a glass rod is rubbed with a silk cloth, electrons from the glass rod are transferred to the piece of silk cloth. Due to this, the glass rod acquires positive (+) charge whereas the silk cloth acquires negative (-) charge. Before rubbing, both the glass rod and silk cloth are neutral and after rubbing the net charge on both of them is also equal to zero. Such similar phenomenon is observed with many other pairs of bodies. Thus, in an isolated system of bodies, charge is neither created nor destroyed, it is simply transferred from one body to the other. So, it is consistent with the law of conservation of charge.

**Question 6.**

Four point charges  $q_A = +2\ \mu\text{C}$ ,  $q_B = -5\ \mu\text{C}$ ,  $q_C = +2\ \mu\text{C}$  and  $q_D = -5\ \mu\text{C}$  are located at the corners of a square ABCD of side 10 cm. What is the force on a charge of  $1\ \mu\text{C}$  placed at the centre of the square?

**Solution:**



Forces of repulsion on  $1\ \mu\text{C}$  charge at O due to  $2\ \mu\text{C}$  charge, at A and C are equal and opposite. Therefore, they cancel. Similarly, forces of attraction on  $1\ \mu\text{C}$  charge at O, due to  $-5\ \mu\text{C}$  charges at B and at D are also equal and opposite. Therefore, these also cancel. Hence, the net force on the charge of  $1\ \mu\text{C}$  at O is zero.

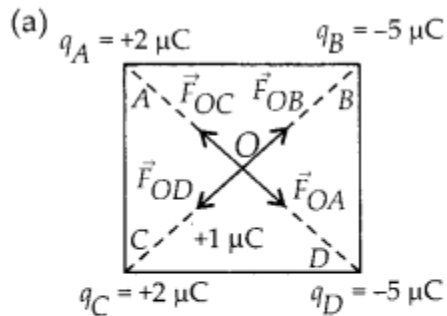
**Question 7.**

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

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

**Solution:**



$$\text{As, } \vec{F}_{OA} = -\vec{F}_{OC} \quad \text{or} \quad \vec{F}_{OA} + \vec{F}_{OC} = 0 \quad \dots(i)$$

So, the net force on charge of  $+1 \mu\text{C}$  at  $O$  is

$$\vec{F} = \vec{F}_{OA} + \vec{F}_{OC} + \vec{F}_{OB} + \vec{F}_{OD} \quad \text{or} \quad \vec{F} = 0$$

A field line cannot have sudden breaks because the moving test charge never jumps from one position to the other.

(b) Two field lines never cross each other at any point/because if they do so, we will obtain two tangents pointing in two different directions of electric field at a point, which is not possible.

### Question 8.

Two point charges  $q_A = 3 \mu\text{C}$  and  $q_B = -3 \mu\text{C}$  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?

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

**Solution:**

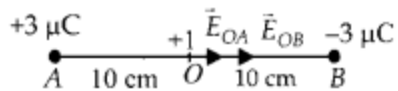
(a) Electric fields at  $O$  due to the charges at  $A$  and  $B$  are

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$$E_{OA} = E_{OB} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

$$= 9 \times 10^9 \times \frac{3 \times 10^{-6} \text{ C}}{(20/2 \times 10^{-2} \text{ m})^2}$$

or  $E_{OA} = E_{OB} = 27 \times 10^5 \text{ N C}^{-1}$



As, they are directed in same direction, so net electric field at midpoint O is

$$E = E_{OA} + E_{OB} = 2E_{OB} = 2 \times 27 \times 10^5$$

or  $E = 5.4 \times 10^6 \text{ N C}^{-1}$  directed along OB.

(b) When test charge  $q_0 = -1.5 \times 10^{-9} \text{ C}$  is placed at point O, it experiences a force

$$F = q_0 E = 1.5 \times 10^{-9} \times 5.4 \times 10^6$$

or  $F = 8.1 \times 10^{-3} \text{ N}$

In direction opposite to that of E i.e. along OA.

### Question 9.

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

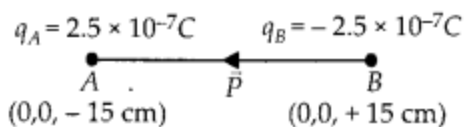
**Solution:**

The total charge of the system is,

$$q_{\text{net}} = q_A + q_B$$

$$\text{or } q_{\text{net}} = 2.5 \times 10^{-7} - 2.5 \times 10^{-7} \text{ or } q_{\text{net}} = 0$$

and the total electric dipole moment of the system is



$$p = q \cdot 2a = 2.5 \times 10^{-7} \text{C} \times 2 \times 15 \times 10^{-2} \text{m}$$

$$\text{or } p = 75 \times 10^{-9} \text{C m}$$

$$\text{or } p = 7.5 \times 10^{-8} \text{C m directed along } BA$$

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### Question 10.

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

**Solution:**

### Question 11.

A Polythene piece rubbed with wool is found to have a negative charge of  $3 \times 10^{-7} \text{C}$ .

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

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

**Solution:**

$$(a) q = ne \text{ or } n =$$

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

$$= 1.875 \times 10^{12}$$

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so,  $1.875 \times 10^{12}$  electrons have transferred from wool to polythene, as polythene acquires negative charge.

(b) Yes, mass of  $1.875 \times 10^{12}$  electrons i.e.,  $m = nm_e = 1.875 \times 10^{12} \times 9.1 \times 10^{-31} \text{ kg} = 1.71 \times 10^{-18} \text{ kg}$  has transferred from wool to polythene

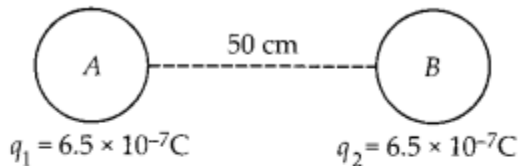
**Question 12.**

(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  $6.5 \times 10^{-7} \text{ C}$  ? 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?

**Solution:**

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



$$\text{or } F = 9 \times 10^9 \frac{(6.5 \times 10^{-7})^2}{(0.5)^2}$$

$$\text{or } F = 1.520 \times 10^{-5} \text{ N}$$

$$(b) q'_1 = 2q_1, q'_2 = 2q_2 \text{ and } r' = \frac{r}{2}$$

$$\text{So, } F' = \frac{1}{4\pi\epsilon_0} \frac{q'_1 \times q'_2}{(r')^2} = \frac{1}{4\pi\epsilon_0} \frac{2q_1 \times 2q_2}{\left(\frac{r}{2}\right)^2}$$

$$\text{or } F' = 16 \times 1.520 \times 10^{-5} = 24.32 \times 10^{-5} \text{ N}$$

$$\text{or } F' = 2.432 \times 10^{-3} \text{ N.}$$

**Question 13.**

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Suppose the spheres A and B in previous question 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?

**Solution:**

$$\begin{array}{cc} \textcircled{A} \textcircled{C} & \textcircled{B} \\ q_1 = 6.5 \times 10^{-7} \text{ C}, & q_2 = 6.5 \times 10^{-7} \text{ C} \\ \\ \textcircled{A} & \textcircled{C} \textcircled{B} \\ q_1'' = 3.25 \times 10^{-7} \text{ C}, & q_{net} = (3.25 + 6.5) \times 10^{-7} \text{ C} \\ & = 9.75 \times 10^{-7} \text{ C} \\ \\ \textcircled{A} & \textcircled{B} \\ q_1'' = 3.25 \times 10^{-7} \text{ C}, & q_2'' = 4.875 \times 10^{-7} \text{ C} \end{array}$$

The new force of repulsion between A and B is

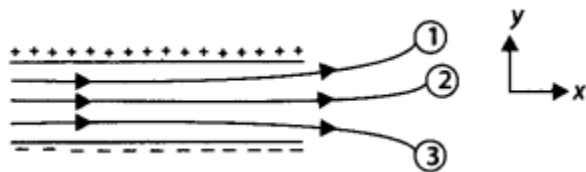
$$F'' = \frac{1}{4\pi\epsilon_0} \frac{q_1'' \times q_2''}{(r'')^2}$$

or  $F'' = 9 \times 10^9 \times \frac{3.25 \times 10^{-7} \times 4.875 \times 10^{-7}}{(0.5)^2}$

or  $F'' = 5.7 \times 10^{-3} \text{ N}$

**Question 14.**

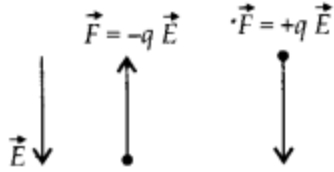
Figure shows tracks of three charged particles in a uniform electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio?



**Solution:**

Particles 1 and 2 are negatively charged as they experience forces in direction opposite to that of electric field E, whereas particle 3 is positively charged as it experience force in the direction of electric field E.

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Particle-3 has the highest charge to mass ratio, as it shows maximum deflection in the electric field.

**Question 15.**

Consider a uniform electric field

$$\vec{E} = 3 \times 10^3 \hat{i} \text{ NC}^{-1}$$

(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?

(b) What is the flux through the same square if the normal to its plane makes a  $60^\circ$  angle with the x-axis?

**Solution:**

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(a) Area of square,  $A = a^2 = 10^2 = 100 \text{ cm}^2$   
 $= 100 \times 10^{-4} \text{ m}^2 = 10^{-2} \text{ m}^2$

As the plane is along  $yz$  plane, so area vector

$\vec{A}$  is directed along  $x$ -axis

*i.e.*,  $\vec{A} = (10^{-2} \hat{i}) \text{ m}^2$

$\therefore$  Electric Flux through the square is

$$\phi = \vec{E} \cdot \vec{A} = (3 \times 10^3 \hat{i}) \cdot (10^{-2} \hat{i}) = 3 \times 10^1$$

or  $\phi = 30 \text{ V-m}$

(b) When normal to plane *i.e.*,  $\vec{A}$  makes an angle of  $60^\circ$  with  $\vec{E}$ , then

$$\phi' = EA \cos 60^\circ = 3 \times 10^3 \times 10^{-2} \times 1/2 = 1.5 \times 10^1$$

or  $\phi' = 15 \text{ V-m}$ .

### Question 16.

What is the net flux of the uniform electric field in previous question through a cube of side 20 cm oriented so that its faces are parallel to the coordinate planes?

**Solution:**

$\phi_{net} = 0$ , As the net electric flux with closed surface like cube in uniform electric

field is equal to zero, because the number of lines entering the cube is the same as the number of lines leaving the cube.

### Question 17.

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  $8.0 \times 10^3 \text{ N m}^2 \text{ C}^{-1}$ .

(a) What is the net charge inside the box?

(b) 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?

**Solution:**

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$$(a) \phi = 8 \times 10^3 \text{ N m}^2 \text{ C}^{-1}$$

$$\text{or } \frac{q}{\epsilon_0} = 8 \times 10^3 \text{ N m}^2 \text{ C}^{-1}$$

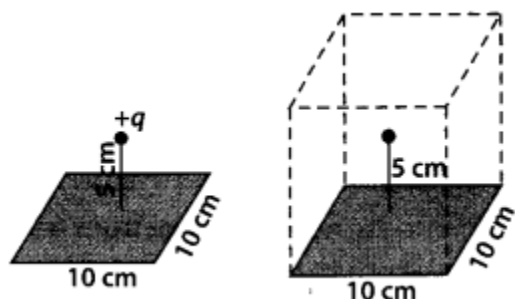
$$\text{or } q = 8 \times 10^3 \epsilon_0 = 8 \times 10^3 \times 8.85 \times 10^{-12}$$

$$\text{or } q = 7.08 \times 10^{-8} \text{ C}$$

$$(b) \text{ As } \phi = 0$$

$$\text{or } \frac{q_{\text{net}}}{\epsilon_0} = 0 \text{ or } q_{\text{net}} = 0$$

So, the net charge enclosed by that closed surface is zero, although it may have some charges inside it.



### Question 18.

A point charge  $+10 \mu\text{C}$  is at a distance of 5 cm directly above the centre of a square of side 10 cm, as shown in figure. What is the magnitude of the electric flux through the square?

### Solution:

Let us assume that the given square be one face of the cube of edge 10 cm. As charge of  $+10 \mu\text{C}$  is at a distance of 5 cm above the centre of a square, so it is enclosed by the cube. Hence by Gauss's theorem, electric flux linked with the cube is

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$$\phi = \frac{q}{\epsilon_0} = \frac{10 \times 10^{-6}}{8.85 \times 10^{-12}} = 1.13 \times 10^6 \text{ N m}^2 \text{ C}^{-1}$$

So, the magnitude of the electric flux through the square is

$$\phi_{sq} = \frac{\phi}{6} = \frac{1.13}{6} \times 10^6 \text{ or } \phi_{sq} = 1.9 \times 10^5 \text{ N m}^2 \text{ C}^{-1}$$

### Question 19.

A point charge of 2.0 pC is at the centre of a cubic Gaussian surface 9.0 cm on edge. What is the net electric flux through the surface?

**Solution:**

$$\begin{aligned} \phi &= \frac{q}{\epsilon_0} = \frac{2 \times 10^{-6}}{8.85 \times 10^{-12}} \\ &= 0.23 \times 10^6 \\ \text{or } \phi &= 2.3 \times 10^5 \text{ N m}^2 \text{ C}^{-1}. \end{aligned}$$

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### Question 20.

A point charge causes an electric flux of  $-1.0 \times 10^3 \text{ Nm}^2 \text{ C}^{-1}$  to pass through a spherical Gaussian surface of 10.0 cm radius centred on the charge.

(a) If the radius of the Gaussian surface were doubled, how much flux would pass through the surface?

(b) What is the value of the point charge?

**Solution:**

(a) On increasing the radius of the Gaussian surface, charge enclosed by it remains the same and hence the electric flux linked with Gaussian surface also remains the same.

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$$(b) \quad \phi = \frac{q}{\epsilon_0} \quad \text{or} \quad q = \phi \epsilon_0$$

$$\text{or} \quad q = -1 \times 10^3 \times 8.85 \times 10^{-12}$$

$$\text{or} \quad q = -8.85 \times 10^{-9} \text{ C} = -8.85 \text{ nC.}$$

### Question 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  $1.5 \times 10^3 \text{ N C}^{-1}$  and points radially inward. What is the net charge on the sphere?

### Solution:

$$r = 20 \text{ cm} = 0.20 \text{ m}, \quad E = 1.5 \times 10^3 \text{ N C}^{-1},$$

$$R = 10 \text{ cm} = 0.1 \text{ m}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \quad \text{or} \quad 1.5 \times 10^3 = 9 \times 10^9 \times \frac{q}{(0.20)^2}$$

$$\text{or} \quad q = \frac{1.5 \times 10^3 \times 0.04}{9 \times 10^9} = 6.67 \times 10^{-9}$$

Since electric field points radially inwards, so charge is negative *i.e.*

$$q = -6.67 \text{ nC.}$$

### Question 22.

A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of  $80.0 \mu\text{C m}^{-2}$ .

(a) Find the charge on the sphere.

(b) What is the total electric flux leaving the surface of the sphere?

### Solution:

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$$R = \frac{2.4 \text{ m}}{2} = 1.2 \text{ m},$$

$$\sigma = 80.0 \mu \text{ C m}^{-2} = 80 \times 10^{-6} \text{ C m}^{-2}$$

$$(a) \text{ As } \sigma = \frac{q}{4\pi R^2}$$

$$\text{So, } q = 4\pi R^2 \times \sigma = 4 \times 3.14 \times (1.2^2) \times 80 \times 10^{-6}$$
$$\text{or } q = 1.45 \times 10^{-3} \text{ C}$$

$$(b) \phi = \frac{q}{\epsilon_0} = \frac{1.45 \times 10^{-3}}{8.85 \times 10^{-12}} = 1.64 \times 10^8 \text{ N m}^2 \text{ C}^{-1}$$

### Question 23.

An infinite line charge produces a field of  $9 \times 10^4 \text{ NC}^{-1}$  at a distance of 2 cm. Calculate the linear charge density.

#### Solution:

$$E = 9 \times 10^4 \text{ N C}^{-1} \quad r = 2 \text{ cm} = 2 \times 10^{-2} \text{ m}$$

$$\text{As } E = \frac{\lambda}{2\pi\epsilon_0 r}$$

$$\text{So, } \lambda = 2\pi\epsilon_0 r \cdot E = \frac{1}{2 \times 9 \times 10^9} \times 9 \times 10^4 \times 2 \times 10^{-2}$$

$$\text{or } \lambda = 1 \times 10^{-7} \text{ C m}^{-1} = 0.1 \mu \text{ C m}^{-1}$$

### Question 24.

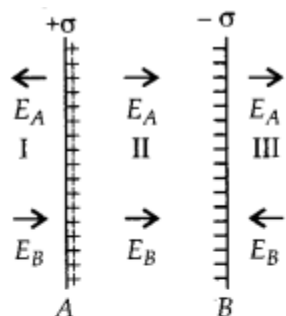
Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitudes  $17.0 \times 10^{-22} \text{ C m}^{-2}$ . What is Electric field in

- (a) the outer region of the first plate.
- (b) the outer region of the second plate, and
- (c) between the plates?

#### Solution:

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As both the plates have same surface charge density  $\sigma$ , so



$$E_A = E_B = \frac{\sigma}{2\epsilon_0}$$

(a) In region-I,

$$E_I = E_B - E_A = \frac{\sigma}{2\epsilon_0} - \frac{\sigma}{2\epsilon_0} \quad \text{or} \quad E_I = 0$$

(b) In region-III,  $E_{III} = E_A - E_B = \frac{\sigma}{2\epsilon_0} - \frac{\sigma}{2\epsilon_0}$   
or  $E_{III} = 0$

(c) In region-II,  $E_{II} = E_A + E_B = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$

$$\text{or} \quad E_{II} = \frac{17.0 \times 10^{-22}}{8.85 \times 10^{-12}} = 1.92 \times 10^{-10} \text{ N C}^{-1}.$$

### Question 25.

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

( $g = 9.81 \text{ m s}^{-2}$ ;  $e = 1.6 \times 10^{-19} \text{ C}$ )

### Solution:

In equilibrium, force due to electric field on the drop balances the weight  $mg$  of drop

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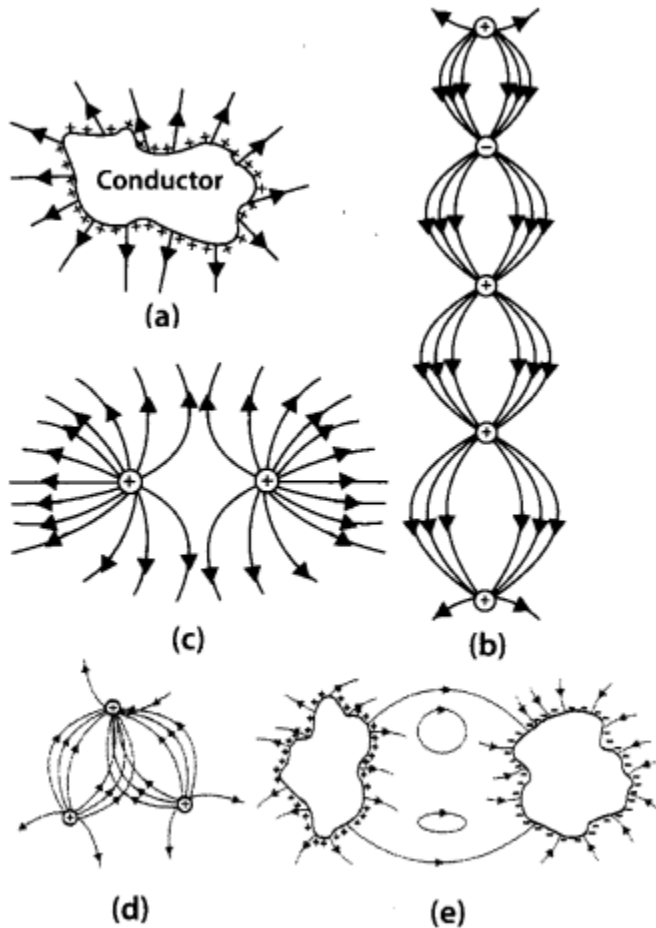


i.e.  $qE = mg$  or  $qE = V\rho g$

or  $qE = \frac{4}{3}\pi r^3 \rho g$  or  $r^3 = \frac{3qE}{4\pi\rho g} = \frac{3 \times 12e \times E}{4\pi\rho g}$

or  $r^3 = \frac{36 \times 1.6 \times 10^{-19} \times 2.55 \times 10^4}{4 \times 3.14 \times 1.26 \times 10^3 \times 9.8}$   
 $= 0.947 \times 10^{-18}$

or  $r = 0.981 \times 10^{-6} \text{ m} = 9.81 \times 10^{-7} \text{ m}$   
 $= 9.81 \times 10^{-4} \text{ mm.}$



### Question 26.

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

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**Solution:**

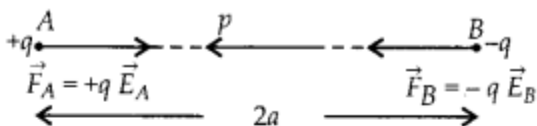
- (a) It is wrong, because electric field lines must be normal to the surface of conductor outside it.
- (b) It is wrong because field lines cannot start or originate from negative charge, and also cannot end or submerge into positive charge.
- (c) It is correct
- (d) It is wrong because electric field lines never intersect each other.
- (e) It is wrong because electric field lines cannot form closed loops.

**Question 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  $10^5 \text{ N C}^{-1}$  per metre. What are the force and torque experienced by a system having a total dipole moment equal to  $10^{-7} \text{ C m}$  in the negative z-direction?

**Solution:**

As electric field increases in positive z-direction from A to B, So



$$E_B = E_A + \frac{dE}{dr} \cdot 2a$$

So, the net force on the electric dipole in electric field is

$$F_{\text{net}} = F_B - F_A = q(E_B - E_A)$$

$$F_{\text{net}} = q \left[ E_A + \frac{dE}{dr} \cdot 2a - E_A \right]$$

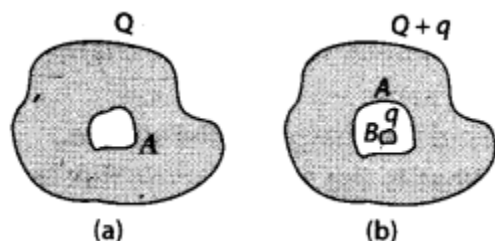
$$F_{\text{net}} = q \cdot 2a \frac{dE}{dr} = p \cdot \frac{dE}{dr}$$

$$F_{\text{net}} = 10^{-7} \times 10^5 \text{ or } F_{\text{net}} = 10^{-2} \text{ N}$$

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directed in direction of FB i.e., from B to A or along  $-z$  direction.

As the two forces on charges of electric dipole are collinear and opposite, so net torque on it is equal to zero.



### Question 28.

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

(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  $Q + q$ . (figure (b))

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

### Solution:

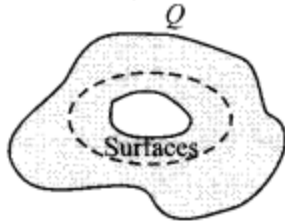
(a) Let us consider a closed surface inside the conductor enclosing the cavity. As electric field inside the conductor is zero,

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so

$$\phi = \oint_s \vec{E} \cdot \vec{ds} = 0 \quad \dots(i)$$

By Gauss's theorem,



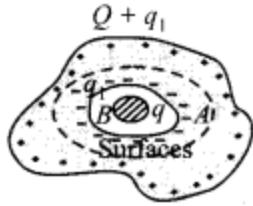
$$\phi = \frac{q_{\text{enclosed}}}{\epsilon_0} \quad \dots(ii)$$

By equations (i) and (ii), we found that

$$\frac{q_{\text{enclosed}}}{\epsilon_0} = 0 \quad \text{or} \quad q_{\text{enclosed}} = 0$$

This shows that there cannot be any charge on the inner surface of conductor at the cavity, so any charge Q given to the conductor will appear only on its outer surface.

(b) Let us consider that the charge  $-q_1$  is induced on the inner surface of conductor A at the cavity, when conductor B of charge q is kept in its cavity. Due to this charge of Q + qt is induced on the outer surface of conductor. Let us construct a closed Gaussian surface S inside the conductor A enclosing its cavity. As, electric field inside conductor is zero, so



$$\phi = \oint_s \vec{E} \cdot \vec{ds} = 0 \quad \dots(\text{iii})$$

But, by Gauss's theorem

$$\phi = \frac{q - q_1}{\epsilon_0} \quad \dots(\text{iv})$$

By equations (iii) and (iv), we get

$$\frac{q - q_1}{\epsilon_0} = 0 \quad \text{or} \quad q - q_1 = 0 \quad \text{or} \quad q_1 = q$$

i.e., equal and opposite charge,  $-q$  is induced on inner surface of conductor A at the cavity,

when conductor B of charge,  $+q$  is kept in its cavity. Hence, the charge on outer surface of conductor is  $Q + q_1 = Q + q$

(c) As we found that electric field inside the cavity of conductor is zero, even on charging the conductor, so the sensitive instrument can be shielded from the strong electrostatic fields in its environment, by covering it with a metallic cover.

### Question 29.

A hollow charged conductor has a tiny hole cut into its surface. Show that the electric field in the hole is

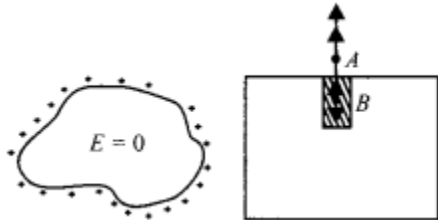
$$\left( \frac{\sigma}{2\epsilon_0} \hat{n} \right)$$

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.where  $\hat{n}$  is the unit vector in the outward normal direction, and  $\sigma$  is the surface charge density near the hole.

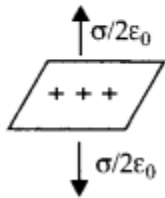
**Solution:**

Inside a charged conductor, the electric field is zero.



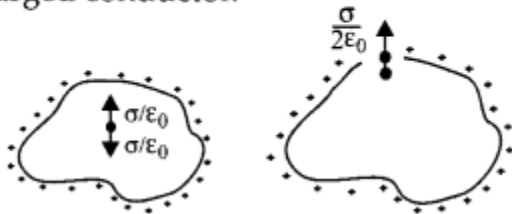
But a uniformly charged flat surface provide

an electric field  $\frac{\sigma}{2\epsilon_0}$  normal to its plane.



If we consider a small flat part on the surface of charged conductor, it certainly provides an

electric field  $\frac{\sigma}{2\epsilon_0}$  inside the conductor, which is nullified by an equal field due to rest of charged conductor.



Now if a hole is made in charged conductor, the field due to small flat part is absent but the field due to rest of charged conductor is present i.e., equal to

$$\frac{\sigma}{2\epsilon_0} \hat{n}$$

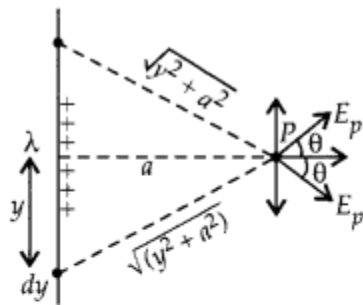
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**Question 30.**

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

**Solution:**

Consider a point P, a unit away from the long charged wire. Electric field due to element  $dy$ ,



$$dE_p = \frac{Q}{4\pi\epsilon_0 r^2}$$

$$Q = \lambda dy$$

$$r^2 = y^2 + a^2$$

$$\Rightarrow dE_p = \frac{\lambda dy}{4\pi\epsilon_0 (y^2 + a^2)} \Rightarrow E_p = \int_{-\infty}^{\infty} dE_p$$

vertical components cancel out and horizontal components are added due to symmetry

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$$\Rightarrow E_p = \int_0^{\infty} \frac{2\lambda dy}{4\pi\epsilon_0(y^2 + a^2)} \times (\cos\theta)$$

$$= \frac{2}{4\pi\epsilon_0} \int_0^{\infty} \frac{\lambda dy}{y^2 + a^2} \times \frac{y}{\sqrt{y^2 + a^2}}$$

$$= \frac{2}{4\pi\epsilon_0} \int_0^{\infty} \frac{\lambda y dy}{(y^2 + a^2)^{3/2}}$$

Take  $y^2 + a^2 = x \Rightarrow 2ydy = dx$

Taking proper limits

$$E_p = \frac{\lambda}{4\pi\epsilon_0} \int_{a^2}^{\infty} \frac{dx}{x^{3/2}} \Rightarrow \left[ \frac{-2\lambda}{4\pi\epsilon_0} \frac{1}{\sqrt{x}} \right]_{a^2}^{\infty} = \frac{\lambda}{2\pi\epsilon_0 a}$$

### Question 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  $+2/3 e$ , and the 'down' quark (denoted by d) of charge  $(-1/3)e$ , 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.

**Solution:**

$$\text{As } u = +\frac{2}{3}e \text{ and } d = -\frac{1}{3}e$$

$$\text{Charge of proton} = +e = \frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e$$

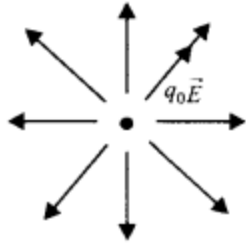
So, configuration of proton is 'uud'

$$\text{Charge of neutron} = 0 = +\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e$$

So, configuration of neutron is 'udd'.

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**Question 32.**

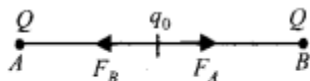
(a) Consider an arbitrary electrostatic field configuration. A small test charge is placed at a null point (i.e., where  $E = 0$ ) of the configuration. Show that the equilibrium of the test charge is necessarily unstable, (b) Verify this result for the simple configuration of two charges of the same magnitude and sign placed at certain distance apart.

**Solution:**

(a) Let us assume that a radial electric field is present with origin as centre. The  $E$  is 0 at origin and a small test charge ' $q_0$ ' is placed at origin. Force on test charge at origin is zero.

$$\vec{F} = q \vec{E} = 0$$

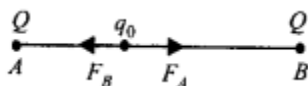
But as the test charge is displaced a little, the electrostatic force will drift it further away so charge is in unstable equilibrium.



$F_A = F_B$  so  $q_0$  is in equilibrium

(b) A test charge placed at mid point of equal charges is in stable equilibrium, for lateral displacement. Initially at mid point position of test charge, two repulsion forces on test charge are equal and opposite.

But on displacing  $q_0$  close to one of the charge, one of the forces become stronger and pushes the charge towards another.



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$F_A > F_B$  so  $q_0$  moves towards B.

**Question 33.**

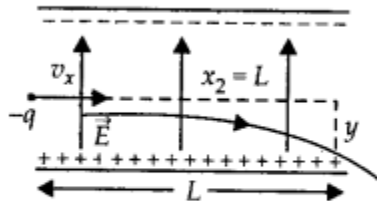
A particle of mass  $m$  and charge  $(-q)$  enters the region between the two charged plates initially moving along  $x$ -axis with speed  $v_x$ . The length of plate is  $L$  and a uniform electric field  $E$  is maintained between the plates. Show that the vertical deflection of the particle at the far edge of the plate is  $\frac{qEL^2}{2mv_x^2}$

$$\frac{qEL^2}{2mv_x^2}$$

**Solution:**

Let the point at which the charged particle enters the electric field, be origin  $O(0, 0)$ , then after travelling a horizontal displacement  $L$ , it gets deflected by displacement  $y$  in vertical direction as it comes out of electric field. So, co-ordinates of its initial position are  $x_1 = 0$  and  $y_1 = 0$  and final position on coming out of electric field are

$$x_2 = L \text{ and } y_2 = y$$



Components of its acceleration are  $a_x = 0$  and

$$a_y = \frac{F}{m} = \frac{qE}{m}$$

and of initial velocity are  $u_x = v_x$  and  $u_y = 0$  so, by 2<sup>nd</sup> equation of motion in horizontal direction,

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$$y_2 - y_1 = u_x t + \frac{1}{2} a_x t^2$$

or  $L - 0 = u_x t + 0$

$$t = \frac{L}{u_x} \quad \dots(i)$$

and by 2<sup>nd</sup> equation of motion in vertical direction,

$$y_2 - y_1 = u_y t + \frac{1}{2} a_y t^2$$

or  $y - 0 = 0 + \frac{1}{2} \cdot \frac{qE}{m} \cdot \left(\frac{L}{v_x}\right)^2 \quad \dots(ii)$

or  $y = \frac{qEL^2}{2mv_x^2}$

This gives the vertical deflection of the particle at the far edge of the plate.

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### Question 34.

Suppose that the particle in question 33 is an electron projected with velocity  $v_x = 2.0 \times 10^6 \text{ m s}^{-1}$ . If  $E$  between the plates separated by 0.5 cm is  $9.1 \times 10^2 \text{ N C}^{-1}$  where will the electron strike the upper plate? ( $|e| = 1.6 \times 10^{-19}$ ,  $m_e = 9.1 \times 10^{-31} \text{ kg}$ )

### Solution:

If the electron is released just near the negatively charged plate, then  $y = 0.5 \text{ cm}$  and hence

$$y = \frac{qEL^2}{2mv_x^2} \quad \text{or} \quad L^2 = \frac{2mv_x^2 y}{qE}$$
$$2 \times 9.1 \times 10^{-31} \text{ kg} \times (2 \times 10^6 \text{ m s}^{-1})^2$$
$$\text{or } L^2 = \frac{\quad \times 0.5 \times 10^{-2} \text{ m}}{1.6 \times 10^{-19} \text{ C} \times 9.1 \times 10^2 \text{ NC}^{-1}}$$
$$\text{or } L^2 = 2.5 \times 10^{-4}$$
$$\text{or } L = 1.6 \times 10^{-2} \text{ m} = 1.6 \text{ cm}$$

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