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1.1 - 1.14 : Electric charges and Fields
Course:NCERT based JEE/NEET, GUJCET   **Class: 12 CBSE/GSEB Board**   Subject: PHYSICS

# NCERT Simplified

2025-26

1.1 INTRODUCTION

Some of the common examples of electric discharge are seeing a spark or hearing a crackle when synthetic clothes or sweater, pariticularly in dry weather is taken off.Another common example of electric discharge is the lightning that is seen in the sky during thunderstorms. A sensation of an electric shock is experienced while opening the door of a car or holding the iron bar of a bus after sliding from our seat. The reason for these experiences is discharge of electric charges through our body, which were accumulated due to rubbing of insulating surfaces.This is due to generation of static electricity.Static means anything that does not move or change with time. **Electrostatics deals with the study of forces, fields and potentials arising from static charges**.

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1.2 ELECTRIC CHARGE

Many pairs of materials were known which on rubbing could attract light objects like straw, pith balls and bits of papers.

It was observed that if two glass rods rubbed with wool or silk cloth are brought close to each other, they repel each other as shown in figure (a).The two strands of wool or two pieces of silk cloth, with which the rods were rubbed, also repel each other. However, the glass rod and wool attracted each other. Similarly, two plastic rods rubbed with cat's fur repelled each other [Figure-b] but attracted the fur. The plastic rod attracts the glass rod [Figure-c] and repel the silk or wool with which the glass rod is rubbed.The glass rod repels the fur.

(a)   (b)   (c)

(d)   (e)   (f)
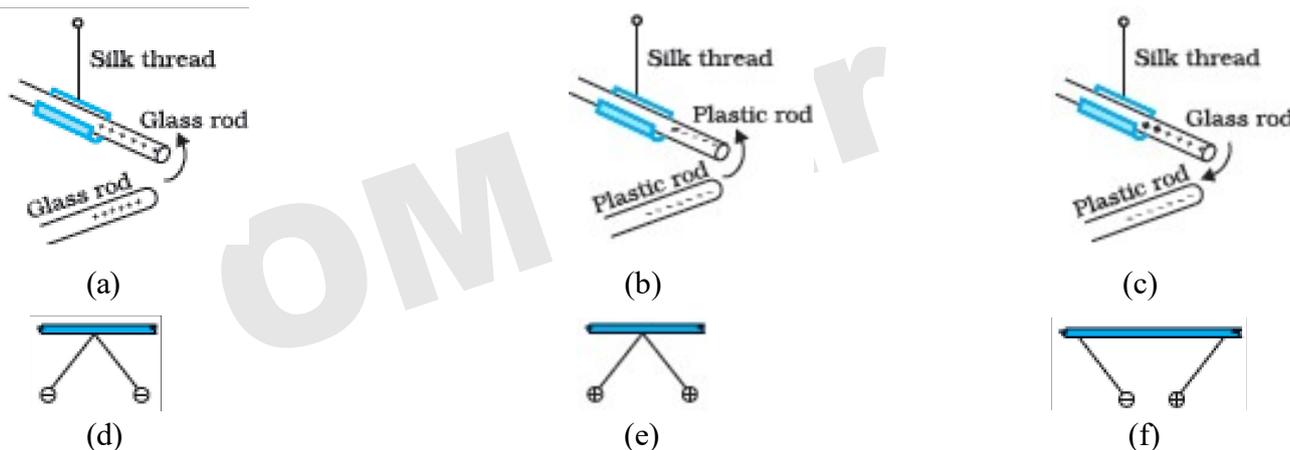
If a plastic rod rubbed with fur is made to touch two small pith balls suspended by silk or nylon thread, then the balls repel each other [Figure-d] and are also repelled by the rod. A similar effect is found if the pith balls are touched with a glass rod rubbed with silk [Figure-e]. A dramatic observation is that a pith ball touched with glass rod attracts another pith ball touched with plastic rod [Figure-f].

After many careful studies by different scientists, it was concluded that there were only **two kinds of** an entity which is called the **electric charge**. **Like charges repel** and **unlike charges attract each other**. The property which differentiates the two kinds of charges is called the **polarity of charge**.

When a glass rod is rubbed with silk, the rod acquires one kind of charge and the silk acquires the second kind of charge. By convention the charge on glass rod is called **positive** and that on silk is termded **negative**.If an object possesses an electric charge, it is said to be electrified or charged. When it has no charge it is said to be **neutral**.

1.3 CONDUCTORS AND INSULATORS

A metal rod held in hand and rubbed with wool will not show any sign of being charged. However, if a metal rod with wooden or plastic handle is rubbed without touching its metal part, it shows signs of charging.

Substances which allow electricity to pass through them easily are called conductors. They have electric charges (electrons) that are comparatively free to move inside the material. Metals, human and animal bodies and earth are conductors.

Substances which do not allow electricity to pass through them are called insulators.Most of the non-metals like glass, porcelain, plastic nylon, wood offer high resistance to the passage of electricity through them.

There is a third category called **semiconductors**, *which offer resistance to the movement of charges which is intermediate between the conductors and insulators*.

When some charge is transferred to a conductor, it readily gets distributed over the entire surface of the conductor. In contrast, if some charge is put on an insulator, it stays at the same place.

When a charged body is brought in contact with the earth, all the excess charge on the body disappears by causing a momentary current to pass to the ground through the connecting conductor. This **process of sharing the charges with the earth is called grounding or earthing**.Earthing provides a safety measure for

electrical circuits and appliances. A thick metal plate is buried deep into the earth and thick wires are drawn from this plate; these are used in buildings for the purpose of earthing near the mains supply. The electric wiring in houses has three wires:live, neutral and earth. The first two carry electric current from the power station and the third is earthed by connecting it to the buried metal plate.Metallic bodies of the electric appliances such as electric iron, refrigerator, TV, are connected to the earth wire.When any fault occurs or live wire touches the metallic body, the charge flows to the earth without damaging the appliance and without causing any injury to the humans; this would have otherwise been unavoidable since the human body is a conductor of electricity.

1.4 BASIC PROPERTIES OF ELECTRIC CHARGE

If the sizes of charged bodies are very small as compared to the distances between them, they are teated as **point charges**.All the charge content of the body is assumed to be concentrated at one point in space.

1.4.1 Additivity of charges

Total charge of a system is obtained by adding them algebraically.

If a system contains n charges $q_1, q_2, q_3, ..., q_n$, then the total charge of the system is

$q_1 + q_2 + q_3 + ... + q_n$. Charges can be positive or negative. Proper signs have to be used while adding the charges in a system.

1.4.2 Charge is conserved

The total charge of the isolated system is always conserved.

It is not possible to create or destroy net charge carried by any isolated system although the charge carrying particles may be created or destroyed in a process. Sometimes nature creates charged particles: a neutron turns into a proton and an electron. The proton and electron thus created have equal and opposite charges and the total charge is zero before and after the creation.

1.4.3 Quantisation of charge

All free **charges are integral multiples of a basic unit of charge denoted by** e. Thus charge q on a body is always given by $q = ne$.

where n is any integer, positive or negative.

The basic unit of charge is the charge that an electron or proton carries.By convention, the chargeon an electron is taken to be negative; therefore charge on an electron is written as $-e$ and that on a proton as $+e$.

The fact that **electric charge is always an integral multiple of** e **is termed as quantisation of charge**.

In the International System (SI) of Units, a unit of charge is called a coulomb and is denoted by the symbol C. **One coulomb is the charge flowing through a wire in** 1 second **if the current is 1 A (ampere)**.

In this system, the value of the basic unit of charge is $e = 1.602192 \times 10^{-19} \ C$.

Thus there are about 6×10^{18} **electrons in a charge of** $-1 \ C$.

....QUESTIONS from CBSE Board Exams..

Q. 1. An object has charge of $1 \ C$ and gains 5.0×10^{18} electrons.The net charge on the object becomes-

(A) $- 0.80 \ C$ (B) $+ 0.80 \ C$ (C) $+ 1.80 \ C$ (D) $+ 0.20 \ C$

[1 mark,CBSE 2022(I)]

Q. 2. In an experiment three microscopic latex spheres are sprayed into a chamber and became charged with charges $+ 3e$, $+ 5e$ and $- 3e$ respectively. All the three spheres came in contact simultaneously for a moment and got separated.Which one of the following are possible values for the final charge on the spheres ?

(A) $+ 5e$, $- 4e$, $+ 5e$ (B) $+ 6e$, $+ 6e$, $- 7e$ (C) $- 4e$, $+ 3.5e$, $+ 5.5e$ (D) $+ 5e$, $- 8e$, $+ 7e$

[1 mark, CBSE 2022(I)]

......................................**QUESTIONS from GSEB Board Exams**.....................................

Q. 1. If a body contains n_1 electrons and n_2 protons, the total amount of charge on the body is _____ .

(A) $\left(n_1^2 + n_2^2\right)e$ (B) $\left(n_1^2 - n_2^2\right)e$ (C) $\left(n_2 + n_1\right)e$ (D) $\left(n_2 - n_1\right)e$ **[1 mark, GSEB 2022]**

Q. 2. If a body contains n_1 protons and n_2 electrons the total amount of charge on the body is _____ .

(A) $\left(n_1 + n_2\right)e$ (B) $\left(n_1 - n_2\right)e$ (C) $\left(n_2 - n_1\right)e$ (D) $\left(n_1 + n_2\right)e^2$ **[1mark, GSEB 2021]**

Q. 3. The charge equivalent of 6×10^{18} electrons is ___

(A) $-1\,C$ (B) $1\,mC$ (C) $1\,C$ (D) $-1\,mC$ **[1 mark, GSEB 2020]**

1.5 COULOMB'S LAW

● When the linear size of charged bodies are much smaller than the distance separating them, the size may be ignored and the charged bodies are treated as **point charges**.

● Coulomb's law states that **the force between two point charges varies inversely as the square of the distance between the charges and is directly proportional to the product of the magnitude of the two charges and acts along the line joining the two charges**.

● If two point charges q_1 and q_2 are separated by a distance r in vacuum, the magnitude of the force

(F) between them is given by $F = k\dfrac{|q_1\,q_2|}{r^2}$ ....(1)

● In SI units, the value of $k = 9 \times 10^9$. From equation (1), when $q_1 = q_2 = 1C$, $r = 1\,m$ and using $k = 9 \times 10^9$, $F = 9 \times 10^9$.

       $1\,C$ **is the charge that when placed at a distance of** $1\,m$ **from another charge of the same magnitude in vacuum experiences an electrical force of repulsion of magnitude** 9×10^9.

● The constant $k = \dfrac{1}{4\pi \in_0} = 9 \times 10^9$. Thus **Coulomb's law is** written as $F = \dfrac{1}{4\pi \in_0}\dfrac{|q_1\,q_2|}{r^2}$

$\in_0$ **is called the permittivity of free space**. The **value of** $\in_0$ in SI units **is** $\in_0 = 8.854 \times 10^{-12}\ \dfrac{C^2}{N\,m^2}$.
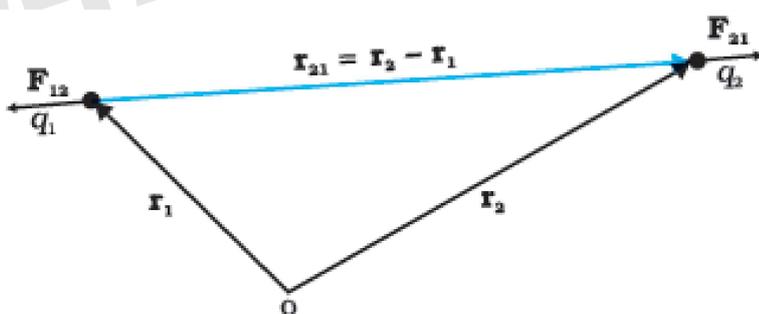
⇒ **Coulomb's law in vector form**:

Figure (a)

• As shown in figure (a), let the position vectors of charges q_1 and q_2 be $\vec{r}_1$ and $\vec{r}_2$ respectively. Force on q_1 due to q_2 is denoted by $\vec{F}_{12}$ and force on q_2 due to q_1 by $\vec{F}_{21}$.

• The two point charges q_1 and q_2 have been numbered 1 and 2 for convenience and the vector leading from 1 to 2 is denoted by $\vec{r}_{21}$: $\qquad \vec{r}_{21} = \vec{r}_2 - \vec{r}_1$.

In the same way vector leading from 2 to 1 is denoted by $\vec{r}_{12}$: $\quad \vec{r}_{12} = \vec{r}_1 - \vec{r}_2 = -\vec{r}_{21}$

• The magnitude of the vectors $\vec{r}_{21}$ and $\vec{r}_{12}$ is denoted by r_{21} and r_{12}, respectively and $r_{21} = r_{12}$

• The direction of the vector is specified by a unit vector along the vector. To denote the direction from 1 to 2 (or from 2 to 1), the unit vectors are defined as follows:

$$\hat{r}_{21} = \frac{\vec{r}_{21}}{r_{21}}, \qquad \hat{r}_{12} = \frac{\vec{r}_{12}}{r_{12}}, \qquad \hat{r}_{21} = -\hat{r}_{12}.$$

• Coulomb's force law between two point charges q_1 and q_2 located at $\vec{r}_1$ and $\vec{r}_2$ is expressed as

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{21}^2} \hat{r}_{21} \qquad\qquad ....(2)$$
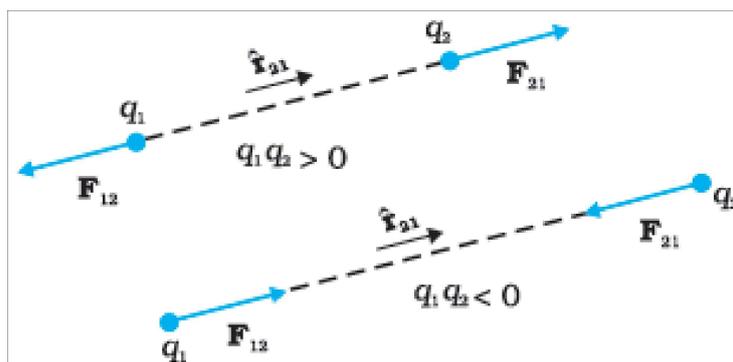

Figure (b)

Equation (2) is valid for any sign of q_1 and q_2 whether positive or negative. If q_1 and q_2 are of the same sign (either both positive or both negaive i.e. $q_1 q_2 > 0$), $\vec{F}_{21}$ is along $\hat{r}_{21}$, which denotes repulsion as like charges repel.

If q_1 and q_2 are of opposite signs $(q_1 q_2 < 0)$, $\vec{F}_{21}$ is along $-\vec{r}_{21} \left(= \vec{r}_{12} \right)$ which denotes attraction as unlike charges attract each other. This is shown in figure (b).

• The force $\vec{F}_{12}$ on charge q_1 due to charge q_2, is written as $\quad \vec{F}_{12} = \frac{1}{4\pi \epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12} = -\vec{F}_{21}$.

• Equation (2) gives the Coulombian force between two charges q_1 and q_2 in vacuum.

....QUESTIONS from CBSE Board Exams..

Q. 1. Two identical conducting balls A and B have charges $-Q$ and $+3Q$ respectively. They are brought in contact with each other and then separated by a distance d apart. Find the nature of the Coulomb force between them. **[1 mark, CBSE 2019]**

Q. 2. Define the term 'dielectric constant' of a material. **[1 mark, CBSE 2019]**

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....QUESTIONS from GSEB Board Exams..

Q. 1. Electric force between electron and proton separated by a distance of $1\,mm$ is , $F_e =$ _____ N

$$\left[K = \frac{1}{4\pi \in_0} \right]$$

(A) $-10^6\, Ke^2$ (B) $-10^{-6}\, Ke^2$ (C) $-10^{-3}\, K^2 e^2$ (D) $-10^{-3}\, Ke^2$ **[1 mark, GSEB 2021]**

Q. 2. The ratio of electric force and gravitational force between a proton and an electron at a certain distance is

(A) 2.4×10^{41} (B) 2.4×10^{39} (C) 10^{41} (D) 3.9×10^{24} **[1 mark, GSEB 2020]**

....NCERT based QUESTIONS from Competitive Exams..

1. The ratio of coulomb's electrostatic force to the gravitational force between an electron and a proton separated by some distance is 2.4×10^{39}. The ratio of the propotionality constant, $k = \dfrac{1}{4\pi \in_0}$ to the Gravitational constant G is nearly (Given that the charge of the proton and electron each $= 1.6 \times 10^{-19}\, C$, the mass of the electron $= 9.11 \times 10^{-31}\, kg$, the mass of the proton $= 1.67 \times 10^{-27}\, kg$):

(A) 10^{20} (B) 10^{30} (C) 10^{40} (D) 10 **[NEET 2022]**

2. Two point charges A and B, having charges $+Q$ and $-Q$ respectively, are placed at certain distance apart and force acting between them is F. If 25% charge of A is transferred to B, then force between the charges becomes:

(A) F (B) $\dfrac{9F}{16}$ (C) $\dfrac{16F}{9}$ (D) $\dfrac{4F}{3}$ **[NEET 2019]**

3. When two spheres having $4Q$ and $-2Q$ charge are placed at a certain distance, the force acting between them is F. Now they are connected by a conducting wire and again separated from each other. Now they are kept at a distance half of the previous one. The force acting between them is.......

(A) $\dfrac{F}{8}$ (B) $\dfrac{F}{2}$ (C) $\dfrac{F}{4}$ (D) F **[GUJCET 2019]**

4. Two identical conducting spheres A and B, carry equal charge. They are separated by a distance much larger than their diameters, and the force between them is F. A third identical conducting sphere, C, is uncharged. Sphere C is first touched to A, then to B, and then removed. As a result, the force between A and B would be equal to :

(A) F (B) $\dfrac{3F}{4}$ (C) $\dfrac{3F}{8}$ (D) $\dfrac{F}{2}$ **[JEE Main 2018]**

5. The electric force acting between two point charges kept at a certain distance in vacuum is $16\, N$. If the same two charges are kept at the same distance in a medium of dielectric constant 8, the electric force acting between them is ___N .

(A) 1024   (B) 128   (C) 16   (D) 2   **[GUJCET 2018]**

6. Suppose the charge of a proton and an electron differ slightly. One of them is $-e$, and other is $(e + \Delta e)$. If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order of

[Given mass of hydrogen $m_h = 1.67 \times 10^{-27}\, Kg$]

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(A) $10^{-20} C$　　　　(B) $10^{-23} C$　　　　(C) $10^{-37} C$　　　　(D) $10^{-47} C$　　　　**[NEET 2017]**

....

1.6 FORCES BETWEEN MULTIPLE CHARGES

● **The principle of superposition:**

Force on any charge due to a number of other charges is the vector sum of all the forces on that charge due to the other charges, taken one at a time. The individual forces are unaffected due to the presence of other charges.

● Consider a system of three charges q_1, q_2 and q_3, as shown in figure (a).
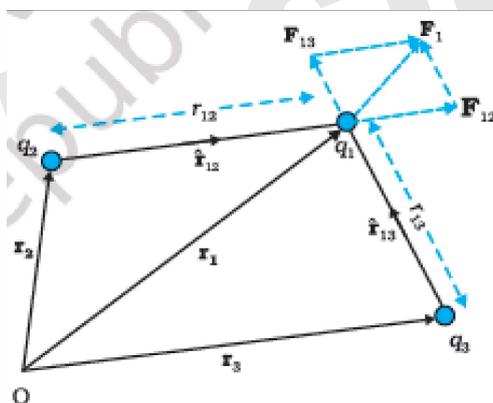
Figure (a)

● The force on one charge, q_1 due to two other charges q_2, q_3 is obtained by vector addition of the forces due to each one of these charges.

● The force on q_1 due to q_2 is $\vec{F}_{12} = \dfrac{1}{4\pi \in_0} \dfrac{q_1 q_2}{r_{12}^2} \hat{r}_{12}$.

● The force on q_1 due to q_3 is $\vec{F}_{13} = \dfrac{1}{4\pi \in_0} \dfrac{q_1 q_3}{r_{13}^2} \hat{r}_{13}$.

● The total force on one charge, q_1 due to two other charges q_2 and q_3 is given by

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13}$$

$$= \dfrac{1}{4\pi \in_0} \dfrac{q_1 q_2}{r_{12}^2} \hat{r}_{12} + \dfrac{1}{4\pi \in_0} \dfrac{q_1 q_3}{r_{13}^2} \hat{r}_{13}$$

● According to the principle of superpositon, in a system of charges $q_1, q_2, ..., q_n$, the force on q_1 due to q_2 is given by Coulomb's law, i.e. it is unaffected by the presence of the other charges $q_3, q_4, ... q_n$.

• The total force $\vec{F}_1$ on the charge q_1, due to all other charges, is then given by the vector sum of the forces:

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \ldots + \vec{F}_{1n}$$

$$= \frac{1}{4\pi \in_0} \left[\frac{q_1 q_2}{r_{12}^2} \hat{r}_{12} + \frac{q_1 q_3}{r_{13}^2} \hat{r}_{13} + \ldots + \frac{q_1 q_n}{r_{1n}^2} \hat{r}_{1n} \right]$$

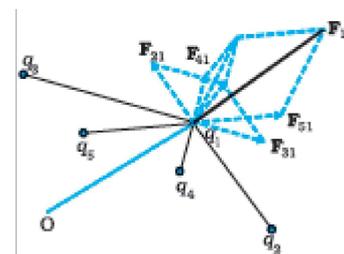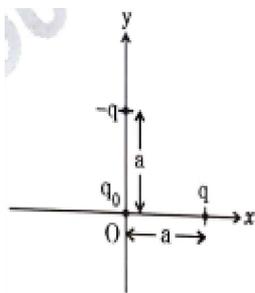$$= \frac{q_1}{4\pi \in_0} \sum_{i=2}^{n} \frac{q_i}{r_{1i}^2} \hat{r}_{1i}$$

Figure (b)

The **vector sum is obtained by the parallelogram law of addition of vectors**.

......................................QUESTIONS from CBSE Board Exams....................................

Q. 1. Three charges q, $-q$ and q_0 are placed as shown in figure. The magnitude of the net force on the

charge q_0 at point O is $\left[k = \frac{1}{(4\pi \in_0)} \right]$.

(A) 0
(B) $\dfrac{2kqq_0}{a^2}$
(C) $\dfrac{\sqrt{2}kqq_0}{a^2}$
(D) $\dfrac{1}{\sqrt{2}} \dfrac{kqq_0}{a^2}$
[1 mark, CBSE 2022(I)]

Q. 2. Four objects W, X, Y and Z each with charge $+q$ are held fixed at four points of a square of side d as shown in the figure. Objects X and Z are on the midpoints of the sides of the square. The electro static force exerted by object W on object X is F. Then the magnitude of the force exerted by object W on Z is
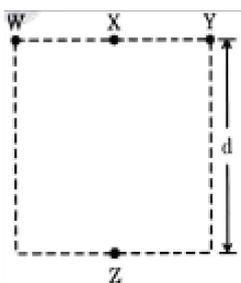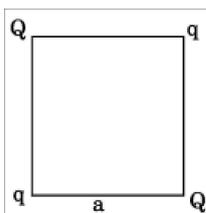
(A) $\dfrac{F}{7}$
(B) $\dfrac{F}{5}$
(C) $\dfrac{F}{3}$
(D) $\dfrac{F}{2}$
[1 mark, CBSE 2022(I)]

Q. 3. Five point charges, each of charge $+q$ are placed on five vertices of a regular hexagon of side 'l'.Find the magnitude of the resultant force on a charge $-q$ placed at the centre of the hexagon.
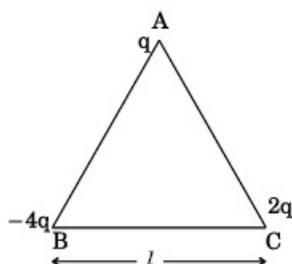
[2 marks, CBSE 2019]

Q. 4. Four point charges Q, q, Q and q are placed at at the corners of a square of side 'a' as shown in the figure.

Find the (a) resultant electric force on a charge Q, and   *(b) potential energy of this system.

[3 marks, CBSE 2018]

Q. 5.(a) Three point charges q, $-4q$ and $2q$ are placed at the vertices of an equilateral triangle ABC of side 'l' as shown in the figure. Obtain the expression for the magnitude of the resultant electric force acting on the charge q.

(b) Find out the amount of the work done to separate the charges at infinite distance.

[3 marks, CBSE 2018]

..........................NCERT based QUESTIONS from Competitive Exams...................................

1. Three charges $+Q$, q, $+Q$ are placed respectively, at distance, 0, $d/2$ and d from the origin, on the axis. If the net force experienced by $+Q$, placed at $x = 0$, is zero, then value of q is :

(A) $+\dfrac{Q}{4}$ (B) $-\dfrac{Q}{4}$ (C) $+\dfrac{Q}{2}$ (D) $-\dfrac{Q}{2}$ **[JEE Main 2019]**

2. Three identical charges are placed on three vertices of a square. If the force acting between q_1 and q_2 is F_{12} and between q_1 and q_3 is F_{13} then $\dfrac{F_{13}}{F_{12}} = $____ .

(A) $\dfrac{1}{2}$ (B) 2 (C) $\dfrac{1}{\sqrt{2}}$ (D) $\sqrt{2}$ **[GUJCET 2018]**

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1.7 ELECTRIC FIELD

● Consider a point charge Q placed in vacuum. This charge Q produces an electric field everywhere in the surrounding. When another point charge q is brought at a distance r from Q, the field there acts on q and produces a force. The electric field produced by the charge Q at a point r is given as

$$\vec{E}(\vec{r}) = \frac{1}{4\pi \in_0} \frac{Q}{r^2} \hat{r}$$ ....(1)

where $\hat{r} = \dfrac{\vec{r}}{r}$ is a unit vector from the origin to the point r.

Equation (1) specifies the value of the electric field for each value of the position vector $\vec{r}$.

● The force $\vec{F}$ exerted by a charge Q on a charge q is $\vec{F} = \dfrac{1}{4\pi \in_0} \dfrac{Qq}{r^2} \hat{r}$ ....(2)

● The **charge q also exerts an equal and opposite force on the charge Q**.

● The electrostatic force between the charges Q and q can be looked upon as an interaction between charge q and the electric field of Q and vice versa.

● If the position of charge q is denoted by vector $\vec{r}$, it experiences a force $\vec{F}$ equal to the charge q multiplied by the electric field $\vec{E}$ at the location of q. Thus

$$\vec{F}(\vec{r}) = q\,\vec{E}(\vec{r})$$ ....(3)

Equation (3) defines the **SI unit of electric field as** N/C.

● Some important remarks:

(1) **Electric field due to a charge Q at a point in space may be defined as the force that a unit positive charge would experience if placed at that point.** The charge Q, which is producing the elctric field is called a **source charge** and the charge q, which tests the effect of a source charge, is called a **test charge**.

(2) The electric field $\vec{E}$ due to Q is independent of q. The electric field $\vec{E}$ due to Q is dependent on the space cordinate $\vec{r}$. For different positions of the charge q all over the space, different values of electric field $\vec{E}$ is obtained. The **field exists at every point in three-dimensional space**.

(3) For a **positive charge, the electric field will be directed radially outwards** from the charge Figure (a).
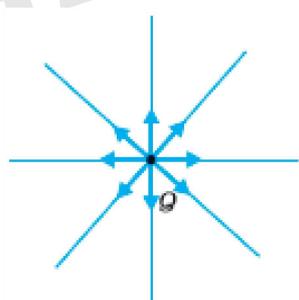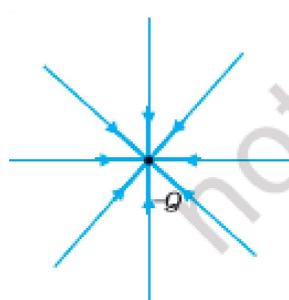

Figure (a)   Figure (b)

If the **source charge is negative, the electric field vector at each point, points radially inwards** Figure (b).

(4) The magnitude of electric field $\vec{E}$ will depend on the distance r of the charge q. Thus at equal distances from the charge Q, the magnitude of its electric field $\vec{E}$ is same. The magnitude of electric field $\vec{E}$ due to a point charge is same on a sphere with the point charge at its centre; i.e. it has a spherical symmetry.

.....................................QUESTIONS from CBSE Board Exams..

Q. 1. Which one of the following statements is correct ?

Electric field due to static charges is

(A) conservative and field lines do not form closed loops.

(B) conservative and field lines form closed loops.

(C) non-conservative and field lines do not form closed loops.

(D) non-conservative and field lines form closed loops.   **[1 mark, CBSE 2025]**

Q. 2. Assertion (A): A negative charge in an electric field moves along the direction of the electric field.

Reason (R): On a negative charge a force acts in the direction of the electric field.

(A) Both (A) & (R) are true and (R) is correct explanation of (A).

(B) Both (A) & (R) are true and (R) is not correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false and (R) is also false.   **[1 mark, CBSE 2021(I)]**

*Q. 3. A simple pendulum consists of a small sphere of mass m suspended by a thread of length l. The sphere carries a positive charge q. The pendulum is placed in a uniform electric field of strength E directed vertically downwards. Find the period of oscillation of the pendulum due to the electrostatic force acting on the sphere, neglecting the effect of the gravitational force.   **[3 marks, CBSE 2019]**

Q. 4. An electron falls through a distance of $1.5 \, cm$ in a uniform electric field of magnitude $2.0 \times 10^4 \, N/C$ (Fig. a).
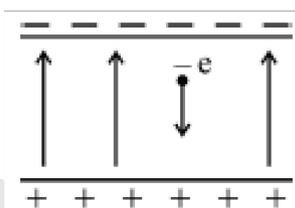

Fig. a

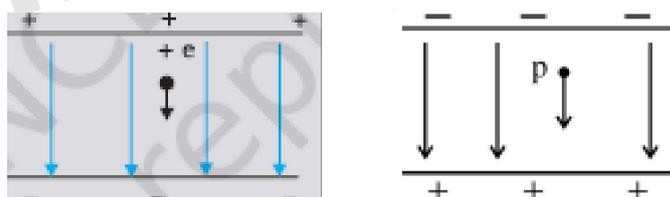Calculate the time it takes to fall through this distance starting from rest.

Fig. b

If the direction of the field is reversed (Fig. b) keeping its magnitude unchanged, calculate the time taken by a proton to fall through this distance starting from rest.   **[3 marks, CBSE 2018]**

....QUESTIONS from GSEB Board Exams...

Q. 1. An electron falls through a distance of $1.5 \, cm$ in a uniform electric field of magnitude $2 \times 10^4 \, NC^{-1}$. The direction of the field is reversed keeping its magnitude unchanged and a proton falls through the same distance. Compute the time of fall in each case. **[3 marks, GSEB 2020]**

.............................NCERT based QUESTIONS from Competitive Exams..............................

1. As shown in the following fig., an electron falls through a distance of $1.5 \, cm$ in a uniform electric field of magnitude $2.0 \times 10^4 \, NC^{-1}$. Find the acceleration of the electron due to the electric field.

$$\left[e = 1.6 \times 10^{-19} C, \; m_e = 9.1 \times 10^{-31} kg \right]$$
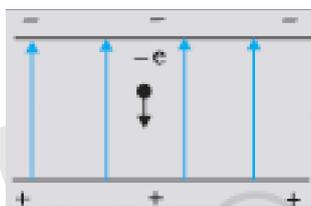
(A) $2.90 \times 10^{19} \, ms^{-2}$ (B) $1.67 \times 10^{27} \, ms^{-2}$ (C) $3.52 \times 10^{15} \, ms^{-2}$ (D) $6.62 \times 10^{34} \, ms^{-2}$

[GUJCET 2021]

2. An electron falls from rest through a vertical distance h in a uniform and vertically upward directed electric field E. The direction of electrical field is now reversed, keeping its magnitude the same. A proton is allowed to fall from rest through the same vertical distance h. The time fall of the electron, in camparison to the time fall of the proton is:

 (A) smaller   (B) 5 times greater   (C) 10 times greater   (D) equal   **[NEET 2018]**

....

$\Rightarrow$ **1.7.1 Electric field due to a system of charges**

● Consider a system of charges $q_1, q_2, ..., q_n$, with position vectors $\vec{r}_1, \vec{r}_2, ..., \vec{r}_n$ relative to some origin O.

● Electric field $\vec{E}_1$ at $\vec{r}$ due to q_1 at $\vec{r}_1$ is given by $\vec{E}_1 = \dfrac{1}{4\pi \in_0} \dfrac{q_1}{r_{1p}^2} \hat{r}_{1p}$.

     where $\hat{r}_{1P}$ is a unit vector in the direction from q_1 to P, and r_{1P} is the distance between q_1 and P.

● Similarly electric field $\vec{E}_2$ at $\vec{r}$ due to q_2 at $\vec{r}_2$ is given by $\vec{E}_2 = \dfrac{1}{4\pi \in_0} \dfrac{q_2}{r_{2P}^2} \hat{r}_{2p}$.

     where $\hat{r}_{2P}$ is a unit vector in the direction from q_2 to P, and r_{2P} is the distance between q_2 and P.

Similar expressions hold for fields $\vec{E}_3, \vec{E}_4, ..., \vec{E}_n$ due to charges $q_3, q_4, ..., q_n$.

● By the superposition principle, the electric field $\vec{E}$ at $\vec{r}$ due to the system of chargs is: (as shown in following figure)
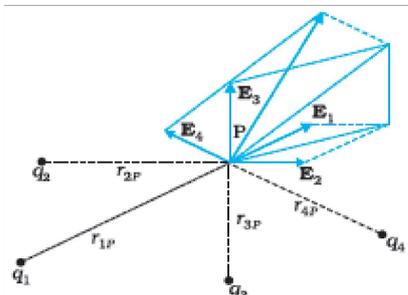
$$\vec{E}(\vec{r}) = \vec{E}_1(\vec{r}) + \vec{E}_2(\vec{r}) + \ldots\ldots + \vec{E}_n(\vec{r})$$

$$= \frac{1}{4\pi \in_0} \frac{q_1}{r_{1P}^2} \hat{r}_{1P} + \frac{1}{4\pi \in_0} \frac{q_2}{r_{2P}^2} \hat{r}_{2P} + \ldots\ldots + \frac{1}{4\pi \in_0} \frac{q_n}{r_{nP}^2} \hat{r}_{nP}$$

$$\vec{E}(\vec{r}) = \frac{1}{4\pi \in_0} \sum_{i=1}^{n} \frac{q_i}{r_{ip}^2} \hat{r}_{ip}$$

$\vec{E}$ is a vector quantity that varies from one point to another point in space and is determined from the positions of the source charges.

....QUESTIONS from CBSE Board Exams...

Q. 1. Two charges $-q$ each are placed at the vertices A and B of an equilateral triangle ABC. If M is the mid-point of AB, the net electric field at C will point along

(A) CA (B) CB (C) MC (D) CM

[1 mark, Set 1, CBSE 2025]

Q. 2. Two identical point charges are placed at the two vertices A and B of an equilateral triangle of side l. The magnitude of the electric field at the third vertex P is E. If a hollow conducting sphere of radius $(l/4)$ is placed at P, the magnitude of the electric field at point P now becomes

(A) $> E$ (B) E (C) $\dfrac{E}{2}$ (D) Zero

[1 mark, Set 2, CBSE 2025]

..................................NCERT based QUESTIONS from Competitive Exams...................................

1. Two point electric charges $+10^{-8}\ C$ and $-10^{-8}\ C$ are placed $0.1\ m$ apart. Find the magnitude of total electric field at the centre of the line joining the two charges.

(A) $3.6 \times 10^4\ NC^{-1}$ (B) $7.2 \times 10^4\ NC^{-1}$ (C) Zero (D) $12.96 \times 10^4\ NC^{-1}$ **[GUJCET 2020]**

2. Charge of $1\ \mu C$ each is placed on the five corners of a regular hexagon of side $1\ m$. The electric field at its centre is .... N/C.

(A) $10^{-6} K$ (B) $\dfrac{6}{5} \times 10^{-6} K$ (C) $5 \times 10^{-6} K$ (D) $\dfrac{5}{6} \times 10^{-6} K$ **[GUJCET 2019]**

Rankers don't solve different questions, they solve questions differently

3. Six charges are placed around a regular hexagon of side length a as shown in the figure. Five of them have charge q, and the remaining one has charge x. The perpendicular from each charge to the nearest hexagon side passes through the centre O of the hexagon and is bisected by the side.
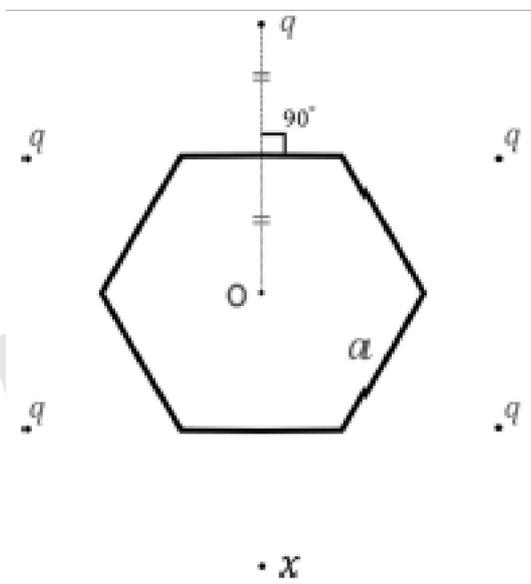
Which of the following statement(s) is (are) correct in SI units ?

(A) When $x = q$, the magnitude of the electric field at O is zero.

(B) When $x = -q$, the magnitude of the electric field at O is $\dfrac{q}{6\pi \in_0 a^2}$.

*(C) When $x = 2q$, the potential at O is $\dfrac{7q}{4\sqrt{3}\pi \in_0 a}$.

*(D) When $x = -3q$, the potential at O is $-\dfrac{3q}{4\sqrt{3}\pi \in_0 a}$.

[JEE Advanced 2022, Paper 1, One or more correct answer]

4. Two point charges $q_1 \left(\sqrt{10}\ \mu C\right)$ and $q_2 \left(- 25\mu C\right)$ are placed on the $x-$ axis at $x = 1\,m$ and $x = 4\,m$ respectively. The electric field (in V/m) at a point $y = 3\,m$ on $y -$ axis is,

$$\left[take\ \frac{1}{4\pi \in_0} = 9 \times 10^9\ Nm^2 C^{-2} \right]$$

(A) $\left(- 63\hat{i} + 27\hat{j}\right) \times 10^2$

(B) $\left(63\hat{i} - 27\hat{j}\right) \times 10^2$

(C) $\left(81\hat{i} - 81\hat{j}\right) \times 10^2$

(D) $\left(- 81\hat{i} + 81\hat{j}\right) \times 10^2$

[JEE Main 2019]

$\Rightarrow$ **1.7.2 Physical significance of electric field**

● Electric field at a point in the space around a system of charges gives the force a unit positive test charge would experience if placed at that point (without disturbing the system).

● It is a characteristic of system of charges and is independent of the test charge which is placed at a point to determine the field.

● Electric field is a vector quantity.
....

1.8 ELECTRIC FIELD LINES

● To represent $\vec{E}$ due to a point charge pictorially, consider a point charge placed at the origin.

● Draw vectors pointing along the direction of the electric field with their lengths proportional to the strength of the field at each point. Since the magnitude of electric field at a point decreases inversely as the square of the distance of that point from the charge, vector gets shorter as moving away from origin, always pointing radially outward. Figure below shows such a picture.
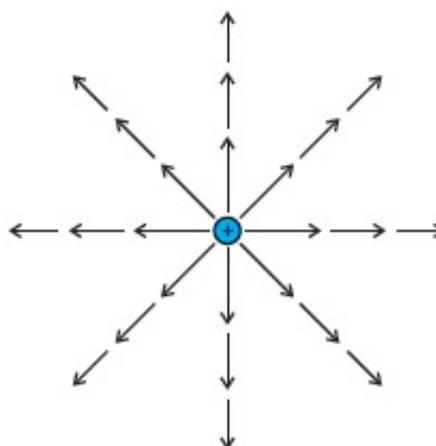

Figure **1**

● In figure (1), each arrow indicates the electric field, i.e. the force acting on a unit positive charge, placed at the tail of that arrow.

● Connect the arrows pointing in one direction and the resulting figure represents a field line.

● Many field lines are obtained, all pointing outwards.

● The magnitude of the field is represented by the density of the field lines. $\vec{E}$ **is strong near the charge, so the density of field lines is more near the charge and the lines are closer**.

● **Away from the charge, the field gets weaker and the density of field lines is less**, resulting in well-separated lines.

● **To show the strength of electric field, relative density of lines in different regions is important, not the number of field lines**.

● Electric field lines are a way of pictorially mapping the electric field around a configuration of charges.

● In general, **electric field line is a curve drawn in such a way that the tangent to it at each point is in the direction of the net field** at that point. An arrow on the curve is necessary to specify the direction of electric field from the two possible directions indicated by a tangent to the curve.

● A field line is a space curve, i.e. a curve in three dimensions.

● The field lines are in 3- dimensional space, though the figure shows them only in plane.

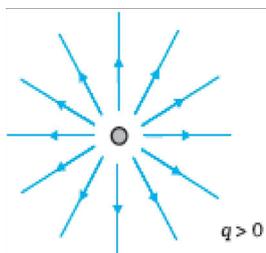• As shown in figure 2, the field lines of a **single positive charge** are radially outward.

Figure **2**

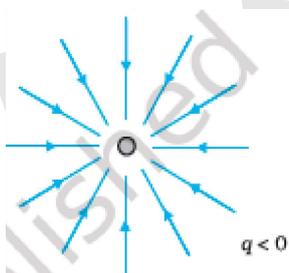• Figure 3 shows the field lines of a **single negative charge** which are radially inward.

Figure **3**

• The field lines around a system of **two positive charges** (q, q) give a vivid pictorial discription of their mutual repulsion as shown in figure 4.
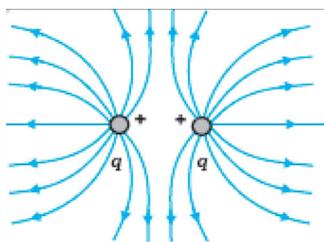

Figure **4**

• In figure 5 the field lines around the configuration of **two equal and opposite charges** $(q, -q)$, a dipole, show the mutual attraction between the charges.
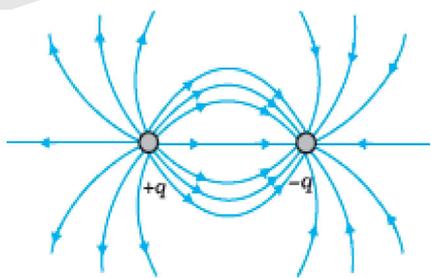

Figure **5**

• The **field lines follow some important properties**:

(1) Field lines **start from positive charges** and **end at negative charges**. If there is a single charge, they may start or end at infinity.

(2) In a charge-free region, **electric field lines can be taken to be continuous curves** without any breaks.

(3) **Two field lines** can **never cross each other**. If they did, the field at the point of intersection will not have a unique direction.

(4) **Electrostatic field lines do not form any closed loops**. This is due to conservative nature of electric field.

....QUESTIONS from CBSE Board Exams..

Q. 1. Which of the diagrams correctly represents the electric field between two charged plates if a neutral conductor is placed in between the plates ?

(A)   (B)
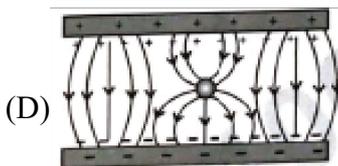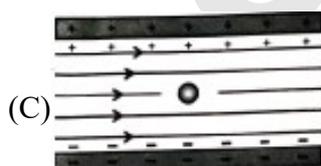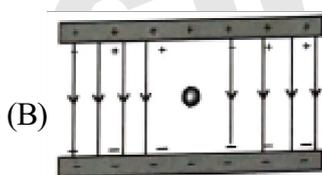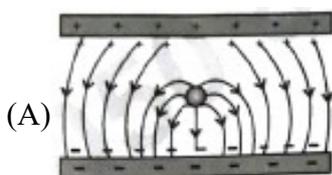
(C)   (D)   **[1 mark, CBSE 2021(I)]**

Q. 2. Draw the pattern of electric field lines, when a point charge $-Q$ is kept near an uncharged conducting plate.   **[1 mark, CBSE 2019]**

Q. 3. A point charge $+Q$ is placed in the vicinity of a conducting surface. Draw the electric field lines between the surface and the charge.   **[1 mark, CBSE 2017]**

....QUESTIONS from GSEB Board Exams..

Q. 1. The electric field line is a curve drawn in such a way that the tangent drawn at any point on the curve gives _____ at that point.
  (A) magnitude of the electric field   (B) direction of the electric field
  (C) both magnitude and direction of the electric field (D) none of the given choices **[1 mark, GSEB 2022]**

Q. 2. Write any four properties of electric field lines.   **[2 marks, GSEB 2022]**

Q. 3. Write any four properties of electric field lines.   **[2 marks, GSEB 2021]**

....

1.9 ELECTRIC FLUX

• **Electric flux** $\Delta\Phi$ through an area element $\Delta\vec{S}$ is defined by $\Delta\Phi = \vec{E} \cdot \Delta\vec{S} = E\,\Delta S \cos\theta$,

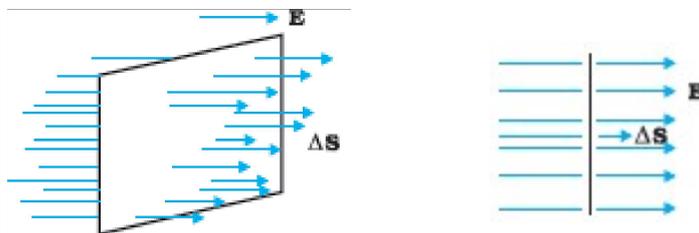 **is proportional to the number of field lines** cutting the area element.

  The θ is the angle between $\vec{E}$ and $\Delta\vec{S}$.

For a closed surface, conventionally, θ is the angle between $\vec{E}$ and the **outward normal** to the area element.

• The unit of electric flux is $\dfrac{Nm^2}{C}$.

• The number of field lines crossing a unit area is a measure of the strength of electric field at that point.

- If a small planar element of area ΔS is placed normal to $\vec{E}$ at a point, number of field lines crossing it is proportional to $E \Delta S$.

- If the area element is tilted by angle θ, the number of field lines crossing the area element will be smaller.
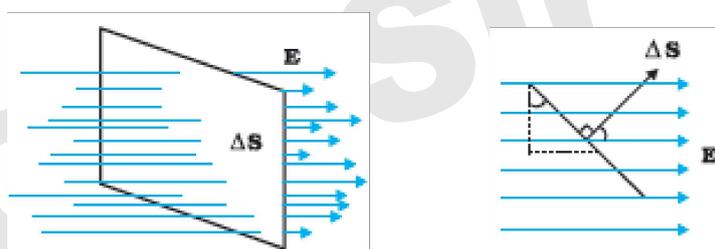
- The projection of the area element normal to E is $\Delta S \cos\theta$.

- Thus the number of field lines crossing ΔS is proportional to $E \Delta S \cos\theta$.

- When $\theta = 90^0$, field lines will be parallel to ΔS and will not cross it at all.

- The direction of an area element $\Delta\vec{S}$ is along its normal. Conventionally, the area element vector at a point on a closed surface equals $\Delta S\,\hat{n}$ where ΔS is the magnitude of the area element and $\hat{n}$ is a unit vector in the direction of **outward normal** at that point.

- To calculate the total electric flux through any given surface, the surface is divided into small area elements, the flux is calculated at each element and addition is carried out, The total flux Φ through a surface S is

$$\Phi \cong \sum \vec{E} \cdot \Delta\vec{S}$$

The approximate sign is put because the electric field $\vec{E}$ is taken to be constant over the small area element.

....QUESTIONS from CBSE Board Exams..

Q. 1. A square sheet of side 'a' is lying parallel to XY plane at $z = a$. The electric field in the region is $\vec{E} = cz^2\hat{k}$. The electric flux through the sheet is

(A) $a^4 c$ (B) $\dfrac{1}{3}a^3 c$ (C) $\dfrac{1}{3}a^4 c$ (D) 0 **[1 mark, CBSE 2021(I)]**

Q. 2. An electric field along the x-axis is given by $\vec{E} = 100\hat{i}\ N/C$ for $x > 0$ and $\vec{E} = -100\hat{i}\ N/C$ for $x < 0$. A right circular cylinder of length $20\ cm$ and radius $5\ cm$ lies parallel to the x-axis, with its centre at the origin and one face at $x = +10\ cm$, the other face at $x = -10\ cm$. Calculate the net outward flux through the cylinder.   **[2 marks, CBSE 2019]**

....QUESTIONS from GSEB Board Exams..

Q. 1. The number of electric field lines coming out of charge _____ kept in a vacuum is 1.13×10^{11}.

$\left(\in_0 = 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}\right)$.

(A) $1\ mC$ (B) $2\ mC$ (C) $2\ C$ (D) $1\ C$ **[1 mark, GSEB 2022]**

Q. 2. Dimension of electric-Flux is _____ .

(A) $M^1 L^{-3} T^3 A^{-1}$ (B) $M^1 L^3 T^{-3} A^{-2}$ (C) $M^1 L^{-3} T^{-3} A^{-1}$ (D) $M^1 L^3 T^{-3} A^{-1}$

[1mark, GSEB 2021]

....

1.10 ELECTRIC DIPOLE

● An **electric dipole** is a pair of equal and opposite point charges q and $-q$, separated by a distance $2a$.

● The direction from q **to** $-q$ **is said to be the direction of the dipole**.

● The midpoint of locations of q and $-q$ is called the centre of the dipole.

● The total charge of the electric dipole is zero.

● The field of the dipole is not zero. Since the charge q and $-q$ are separated by some distance, the electric fields due to them, when added, do not exactly cancel out.

● At distances much larger than the separation of the two charges forming a dipole, the fields due to q and $-q$ nearly cancel out.

● The **dipole moment vector of an electric dipole** is defined as $\vec{p} = q \times 2a\ \hat{p}$.

It is a vector quantity whose **magnitude is charge** q **times the separation** $2a$ (between the pair of charges q, $-q$) and **the direction is along the line from** $-q$ **to** q.

$\Rightarrow$ **1.10.1 The field of an electric dipole**

● The electric field of the pair of charges at any point in space is found from Coulomb's law and the superpositon principle.

$\Rightarrow$ **For points on the axis (Electric field when the point is on the dipole axis):**

● Let the point P be at distance r from the centre of the dipole on the side of the charge q as shown in figure below:
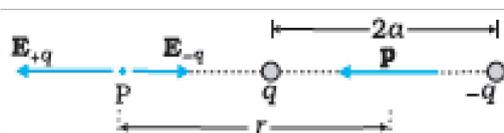
• Electric field due to $-q$ charge is $\vec{E}_{-q} = -\dfrac{q}{4\pi \in_0 (r+a)^2} \hat{p}$ ....(1)

and Electric field due to q charge is $\vec{E}_{+q} = \dfrac{q}{4\pi \in_0 (r-a)^2} \hat{p}$, ...(2)

where $\hat{p}$ is the unit vector along the dipole axis (from $-q$ to q).

• The total field at P is

$$\vec{E} = \vec{E}_{+q} + \vec{E}_{-q}$$

$$= \frac{q}{4\pi \in_0} \left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2} \right] \hat{p}$$

$$= \frac{q}{4\pi \in_0} \frac{4ar}{\left(r^2 - a^2\right)^2} \hat{p}$$

• For $r >> a$, $\vec{E} = \dfrac{4qa}{4\pi \in_0 r^3} \hat{p}$

• As $\left(p = 2aq\right)$ and

$$\hat{p} = \frac{\vec{p}}{|p|} = \frac{\vec{p}}{2aq}$$

$$\therefore \vec{p} = 2aq \, \hat{p}$$

in terms of dipole moment , **the electric field of a dipole at large distances at a point of the dipole axis is:**

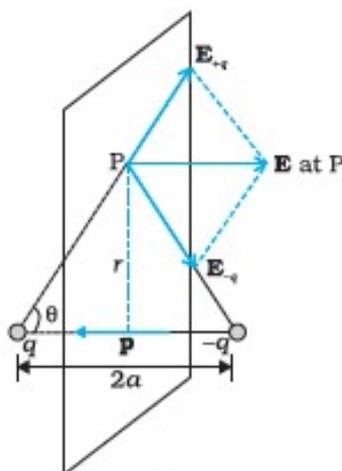$$\vec{E} = \frac{2\vec{p}}{4\pi \in_0 r^3} \qquad \left(r >> a\right).$$

$\Rightarrow$ **For points on the equatorial plane (Electric field when the point is on the equator):**

• The magnitudes of the electric fields due to the two charges are given by $E_{+q} = \dfrac{q}{4\pi \in_0} \dfrac{1}{(r^2 + a^2)}$ and

$E_{-q} = \dfrac{q}{4\pi \in_0} \dfrac{1}{(r^2 + a^2)}$. Here $E_{+q} = E_{-q}$.

• The directions of $\vec{E}_{+q}$ and $\vec{E}_{-q}$ are shown in the figure.Their components normal to the dipole axis cancel away.

- Their components along the dipole axis add up. The total electric field is opposite to $\hat{p}$. The total electric field is

$$\vec{E} = \left(E_{+q} + E_{-q}\right)\cos\theta\ \hat{p}$$

$$= -\frac{2qa}{4\pi \in_0 \left(r^2 + a^2\right)^{3/2}}\ \hat{p}$$

- At large distances $r >> a$, $\vec{E} = -\dfrac{2qa}{4\pi \in_0\ r^3}\ \hat{p}$

- As $(p = 2aq)$, and

$$\hat{p} = \frac{\vec{p}}{|p|} = \frac{\vec{p}}{2aq}$$

$$\therefore \vec{p} = 2aq\ \hat{p}$$

in terms of dipole moment , the **electric field of a dipole at large distances at a point of the equatorial**

plane is: $\quad \vec{E} = -\dfrac{\vec{p}}{4\pi \in_0\ r^3}\quad (r >> a)$.

NOTE: *The dipole field at **large distances** falls off **as** $\dfrac{1}{r^3}$ not as $\dfrac{1}{r^2}$.*

....QUESTIONS from CBSE Board Exams...

Q. 1. Consider two identical dipoles D_1 and D_2. Charges $-q$ and q of dipole D_1 are located at $(0,0)$ and $(a,0)$ and that of dipole D_2 at $(0,a)$ and $(0,2a)$ in $x - y$ plane, respectively. The net dipole moment of the system is

(A) $qa(\hat{i} + \hat{j})$ (B) $-qa(\hat{i} + \hat{j})$ (C) $qa(\hat{i} - \hat{j})$ (D) $-qa(\hat{i} - \hat{j})$

[1 mark, Set 3, CBSE 2025]

Q. 2. A point charge is situated at an axial point of a small electric dipole at a large distance from it. The charge experiences a force F .If the distance of the charge is doubled,the force acting on the charge will become

(A) $2F$ (B) $F/2$ (C) $F/4$ (D) $F/8$ **[1 mark, CBSE 2020]**

Q. 3. Obtain an expression for the electric field at a point on the equatorial line of an electric dipole.

[2 marks, CBSE 2019]

Q. 4.

(a) Derive an expression for the electric field at any point on the equatorial line of an electric dipole.

(b) Two identical point charges, q each, are kept $2\,m$ apart in air. A third point charge Q of unknown magnitude and sign is placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of Q .   **[5 marks, CBSE 2019]**

Q. 5. Derive an expression for the electric field at a point on the axis of an electric dipole of dipole moment $\vec{p}$. Also write its expression when the distance $r \gg$ the length 'a' of the dipole.   **[2 marks, CBSE 2019]**

....**QUESTIONS from GSEB Board Exams..**..

Q. 1. For Electric dipole,

(a) At any point on the axis   (b) At any point on the equatorial plane

obtain the equations of an electric field.   **[4 marks, GSEB 2021]**

Q. 2. Electric field due to dipole at large distance (r) falls off as ____

(A) $\dfrac{1}{r}$ (B) $\dfrac{1}{r^3}$ (C) $\dfrac{1}{r^2}$ (D) $\dfrac{1}{r^4}$ **[1 mark, GSEB 2020]**

.................................**NCERT based QUESTIONS from Competitive Exams**...................................

1. Electrical field intensity due to an electric dipole on it's axis at distance $x\,(x \gg a)$ and on the equatorial at distance $y\,(y \gg a)$ are same. What is the ratio of x and y ?

(A) $\sqrt[3]{2}:1$ (B) $\sqrt{2}:1$ (C) $1:\sqrt[3]{2}$ (D) $1:2$ **[GUJCET 2021]**

2. Determine the electric dipole moment of the system of three charges, placed on the vertices of an equilateral triangle, as shown in the figure:
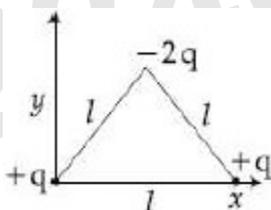

(A) $(ql)\dfrac{\hat{i}+\hat{j}}{\sqrt{2}}$ (B) $-\sqrt{3}\,ql\,\hat{j}$ (C) $2ql\,\hat{j}$ (D) $\sqrt{3}\,ql\dfrac{\hat{i}-\hat{j}}{\sqrt{2}}$ **[JEE Main 2019]**

⇒ **1.10.2 Physical significance of dipoles**

● In most molecules, the centres of positive charges and of negative charges lie at the same place. Therfore their dipole moment is zero. Example: CO_2 and CH_4. These molecules develop a dipole moment when an electric field is applied.

● In some molecules, the centres of negative charges and of positive charges do not coincide. Therefore they have a permanent electric dipole moment, even in the absence of an electric field. Such molecules are called **polar molecules**. Example: H_2O.

1.11 DIPOLE IN A UNIFORM EXTERNAL FIELD
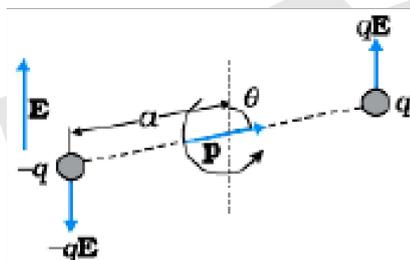
● Consider a permanent dipole of dipole moment $\vec{p}$ in a uniform external field $\vec{E}$ as shown in figure.

● There is a force $q\vec{E}$ on q and a force $-q\vec{E}$ on $-q$. The **net force on the dipole is zero**, since $\vec{E}$ is uniform.

● As the charges are separated, so the forces act at different points, resulting in a **torque** on the dipole.

● When the net force is zero, the torque (couple) is independent of the origin.

● The **magnitude torque equals the magnitude of each force multiplied by the arm of the couple** (perpendicular distance between the two antiparallel forces).

Magnitude of torque

$$= qE \times 2a \sin \theta$$

$$= 2qaE \sin \theta$$

The **direction of torque is normal to the plane of the paper**, coming out of it.

● The magnitude of $\vec{p} \times \vec{E}$ is also $pE \sin \theta$ and its direction is normal to the paper, coming out of it.

Thus   torque $\vec{\tau} = \vec{p} \times \vec{E}$.

● This **torque will tend to allign the dipole with the field** $\vec{E}$. When $\vec{p}$ **is alligned with** $\vec{E}$,**the torque is zero**.
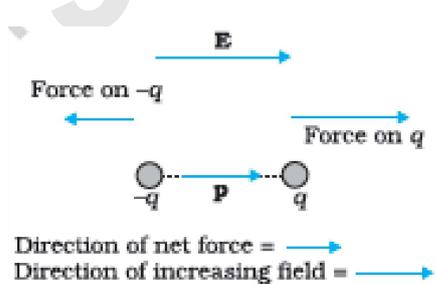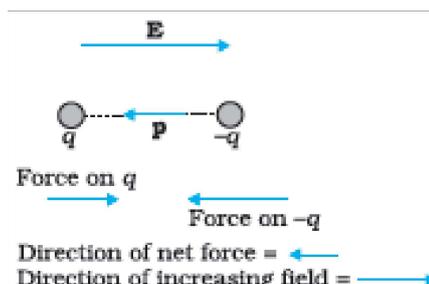
⇒ **Dipole in non-uniform field:**

Figure 1

Figure 2

• When a dipole is kept in non-uniform field, the net force will be non-zero and also in general, a torque will be there on the system.

• Consider a simple situation when $\vec{p}$ is parallel to $\vec{E}$ **(Figure 1)** or $\vec{p}$ antiparallel to $\vec{E}$ **(Figure 2)**.

In either case, the net torque is zero but there is a net force on the dipole if $\vec{E}$ is not uniform.

• When $\vec{p}$ **is parallel to** $\vec{E}$ **, the dipole has a net force in the direction of increasing field (Figure 1)**.

• When $\vec{p}$ **is antiparallel to** $\vec{E}$ **,the net force on the dipole is in the direction of decreasing field (Figure 2)**.

• In general, the force depends on the orientation of $\vec{p}$ with respect to $\vec{E}$.

.....................................**QUESTIONS from CBSE Board Exams.**...

Q. 1. Derive an expression for the torque acting on an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. Write the direction along which the torque acts. **[2 marks, CBSE 2019]**

Q. 2.

(a) An electric dipole of dipole moment $\vec{p}$ is held in a uniform electric field $\vec{E}$. Show that the torque acting on the dipole is given be $\vec{p} \times \vec{E}$ **.**

(b) How much work is required in turning the electric dipole from the position of most stable equilibrium to that of most unstable ? **[3 marks, CBSE 2019]**

Q. 3.

(a) Derive an expression for the electric field E due to a dipole of dipole of length '$2a$' at a point distant r from the centre of the dipole on the axial line.

(b) Draw a graph of E versus r for $r \gg a$.

(c) If this dipole were kept in a uniform external electric field E_0 ,diagrammatically represent the position of the dipole in stable and unstable equilibrium and write the expressions for the torque acting on the dipole in both the cases. **[5 marks, CBSE 2017]**

.............................**NCERT based QUESTIONS from Competitive Exams**...................................

1. An electric dipole with dipole moment $4 \times 10^{-9} \, NC^{-1}$ is alligned at 60^0 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.

(A) $17.3 \times 10^{-5} \, Nm$ (B) $1.73 \times 10^{-5} \, Nm$ (C) $1.73 \times 10^{-4} \, Nm$ (D) $17.3 \times 10^{-4} \, Nm$

[GUJCET 2022]

2. An electric dipole is placed in a nonuniform electric field, then ....

(A)Torque acting on it is always zero   (B)The resultant force acting on the dipole may be zero

(C)Torque acting on it may be zero   (D)The resultant force acting on the dipole is always zero

[GUJCET 2019]

1.12 CONTINUOUS CHARGE DISTRIBUTION

• To work with continuous charge distributions, charge density is used.
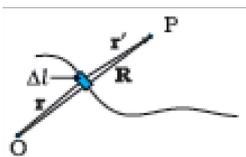
$\Rightarrow$ **Surface charge density (** σ **):**
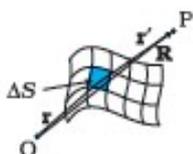
● As shown in figure, consider an area element ΔS on the surface of conductor (which is very small on the macroscpic scale but big enough to include a very large number of electrons) carrying charge ΔQ .

● A surface charge density σ at the area element is defined by $\sigma = \dfrac{\Delta Q}{\Delta S}$.

● The units for surface charge density σ are $\dfrac{C}{m^2}$.

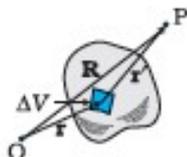$\Rightarrow$ **Linear charge density (λ):**

● The linear charge density λ of a wire is defined by $\lambda = \dfrac{\Delta Q}{\Delta l}$.

where Δl is a small line element of wire on the macroscopic scale i.e. it includes a large number of microscopic charged constituents and ΔQ is the charge contained in that line element.

● The units for line charge density λ are $\dfrac{C}{m}$.

$\Rightarrow$ **Volume charge density (ρ):**

● The volume charge density (sometimes called charge density) ρ is defined by $\rho = \dfrac{\Delta Q}{\Delta V}$.

where ΔQ is the charge included in the macroscopically small volume element ΔV that includes a large number of microscopically small volume element that includes a large number of microscopic charged constituents.

● The units for volume charge density ρ are $\dfrac{C}{m^3}$.

....QUESTIONS from GSEB Board Exams..

Q. 1. Unit of surface charge density (σ) is ____

(A) $\dfrac{C}{m^3}$ (B) $\dfrac{C}{m}$ (C) $\dfrac{C}{m^2}$ (D) Cm **[1 mark, GSEB 2020]**

Q. 2. A uniformly charged conducting sphere of $2.4\ m$ diameter has a surface charge density of $80\ \mu C\ m^{-2}$. The charge on the sphere is _____ mC .

(A) 5.41   (B) 4.51   (C) 1.45   (D) 45.1   **[1 mark, GSEB 2022]**

....NCERT based QUESTIONS from Competitive Exams.....................................

1. Two large,thin metal plates are parallel and close to each other.On their inner faces, the plates have surface charge densities of same signs and of magnitude $17.7 \times 10^{-22} \ C/m^2$ .What is E in the outer region of the second plate ?

(A) $4 \times 10^{-10} \ NC^{-1}$ (B) $2 \times 10^{-10} \ NC^{-1}$ (C) $1 \times 10^{-10} \ NC^{-1}$ (D) Zero   **[GUJCET 2021]**

....

1.13 GAUSS'S LAW

● **Gauss's law states that electric flux through a closed surface** S

$$= \frac{q}{\in_0} \ ,$$

   where q = **total charge enclosed by** S .

● This law implies that the total electric flux through a closed surface is zero if no charge is enclosed by the surface.

⇒ **Proof of Gauss's law through electrostatics:**

● Consider the total flux through a sphere of radius r , which encloses a point charge q at its centre.

● Divide the sphere into small area elements as showin in figure.
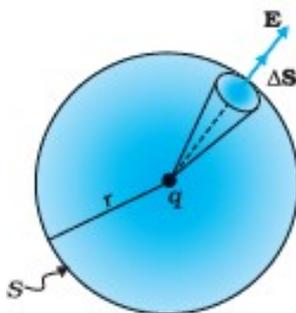
● The flux through an area element $\Delta \vec{S}$ is

$$\Delta \Phi = \vec{E} \cdot \Delta \vec{S}$$

$$= \frac{q}{4\pi \in_0 \ r^2} \hat{r} \, \Delta \vec{S}$$

   where electric field $\vec{E}$ due to a single charge q is $\vec{E} = \frac{q}{4\pi \in_0 \ r^2} \hat{r}$.

   The unit vector $\hat{r}$ is along the radius vector from the centre to the area element.

● As the normal to a sphere at every point is along the radius vector at that point, the area element $\Delta \vec{S}$ and $\hat{r}$ have the same direction.Thus

$$\Delta \Phi = \frac{q}{4\pi \in_0 \ r^2} \Delta S \ \text{ since the magnitude of unit vector is 1.}$$

• The total flux through the sphere is obtained by adding up flux through all the different area elements:

$$\Phi = \sum_{all\ \Delta S} \frac{q}{4\pi \in_0 r^2} \Delta S$$

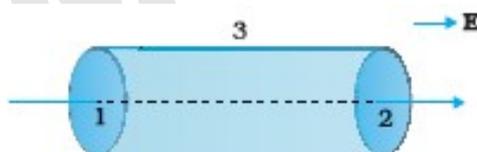• As each area element of the sphere is at the same distance r from the charge,

$$\Phi = \frac{q}{4\pi \in_0 r^2} \sum_{all\ \Delta S} \Delta S = \frac{q}{4\pi \in_0 r^2} S$$

• Now the total area of the sphere, $S = 4\pi r^2$.

   Thus

$$\Phi = \frac{q}{4\pi \in_0 r^2} \times 4\pi r^2 = \frac{q}{\in_0}$$

$\Rightarrow$ **Calculation of the flux of uniform electric field through the surface of a cylinder:**

• Consider a closed cylindrical surface with its axis parallel to the uniform field $\vec{E}$ as shown in figure.

• The total flux through the surface is $\Phi = \Phi_1 + \Phi_2 + \Phi_3$, where Φ_1 and Φ_2 represent the flux through the surfaces 1 and 2 (of circular cross-section) of the cylinder and Φ_3 is the flux through the curved cylindrical part of the closed surface.

• As the normal to the surface 3 at every point is perpendicular to $\vec{E}$, therefore $\Phi_3 = 0$.

• The outward normal to 2 is along $\vec{E}$ while the outward normal to 1 is opposite to $\vec{E}$, therefore

$$\Phi_1 = -E S_1, \quad \Phi_2 = +E S_2$$

   Also $S_1 = S_2 = S$, where S is the area of circular cross-section. Thus, the total flux is zero.

• **Whenever the net electric flux through a closed surface is zero, the total charge contained in the closed surface is zero**.

....**QUESTIONS from CBSE Board Exams**..

Q. 1.(i) What is difference between an open surface and a closed surface ?

   Draw elementary surface vector $d\vec{S}$ for a spherical surface S.

   (ii) Define electric flux through a surface. Give the significance of a Gaussian surface. A charge outside a Gaussian surface does not contribute to total electric flux through the surface. Why ?

   (iii) A small spherical shell S_1 has point charges $q_1 = -3\mu C$, $q_2 = -2\mu C$ and $q_3 = 9\mu C$ inside it. This shell is enclosed by another big spherical shell S_2. A point charge Q is placed in between the two surfaces S_1 and S_2. If the electric flux through the surface S_2 is four times the flux through surface S_1, find charge Q.   **[5 marks, Set 3, CBSE 2025]**

**Q. 2.** If the net electric flux through a closed surface is zero, then we can infer

(A) no net charge is enclosed by the surface.

(B) uniform electric field exists within the surface.

(C) electric potential varies from point to point inside the surface.

(D) charge is present inside the surface. **[1 mark, CBSE 2020]**

Q. 3.

(a) Define electric flux. Is it a scalar or a vector quantity ?

A point charge is a at a distance of $\dfrac{d}{2}$ directly above the centre of a square of side d as shown in the figure. Use the Gauss' law to obtain the expression for the electric flux through the square.
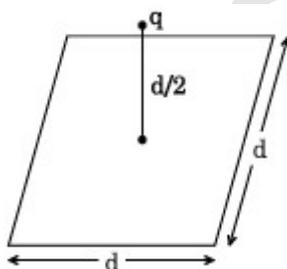
(b) If the point charge is now moved to a distance d from the centre of the square and the side of the square is doubled, explain how the electric flux will be affected. **[5 marks, CBSE 2018]**
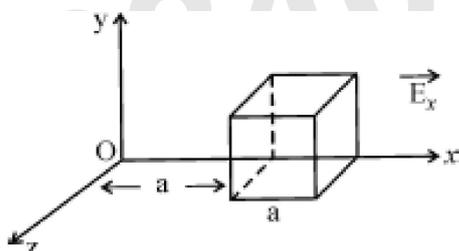
Q. 4. Define electric flux. Is it a scalar or a vector quantity ?

A point charge causes an electric flux of $-1 \times 10^3 \ Nm^2/C$ to pass through a spherical Gaussian surface of $10.0 \ cm$ radius centred on the charge. What is the value of the point charge?

Does the flux passing through the surface depend on the radius of the Gaussian surface enclosing the charge? Justify your answer. **[3 marks, CBSE 2018]**

Q. 5. Define electric flux and write its SI unit. The electric field components in the figure shown are:

$E_x = \alpha x$, $E_y = 0$, $E_z = 0$ where $\alpha = \dfrac{100N}{Cm}$. Calculate the charge within the cube, assuming $a = 0.1 \ m$.

[3 marks, CBSE 2018]

Q. 6. A point charge causes an electric flux of $-4\pi \times 10^3 \ Nm^2/C$ to pass through a spherical Gaussian surface of $10.0 \ cm$ radius centred on the charge. (i) Calculate the value of the point charge. (ii) If the radius of the Gaussian surface were doubled, how much flux would pass through the surface ? Justify your answer. **[3 marks, CBSE 2017]**

...................................**NCERT based QUESTIONS from Competitive Exams**...................................

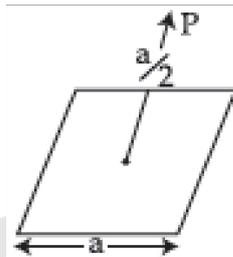**1.** Dimensional formula of electric flux =

(A) $M^1 L^{-3} T^{-3} A^{-1}$ (B) $M^1 L^3 T^{-3} A^{-1}$ (C) $M^1 L^3 T^3 A^{-1}$ (D) $M^{-1} L^3 T^{-3} A^{-1}$ **[GUJCET 2022]**

2. If charge q is placed on one of the vertex of a cube. Then flux passing through any one surface of cube is ..

(A) $\dfrac{q}{\varepsilon_0}$ (B) $\dfrac{q}{6\in_0}$ (C) $\dfrac{q}{24\in_0}$ (D) None of these **[GUJCET 2020]**

3. A charge Q is placed at a distance a/2 above the centre of the square surface of edge a as shown in the figure.
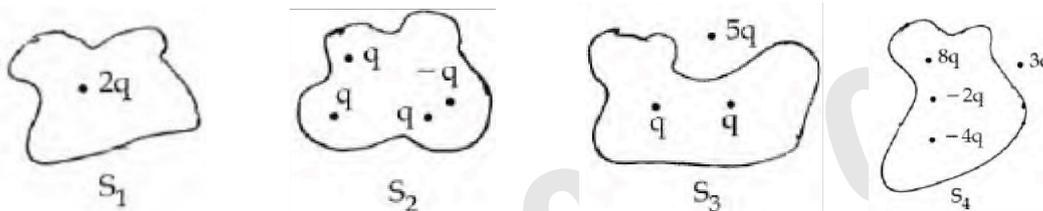

The electric flux through the square surface is:

(A) $\dfrac{Q}{\in_0}$ (B) $\dfrac{Q}{2\in_0}$ (C) $\dfrac{Q}{3\in_0}$ (D) $\dfrac{Q}{6\in_0}$ **[JEE Main 2018 Online]**

4. When a $10\mu C$ charge is enclosed by a closed surface, the flux passing through the surface is φ. Now another $10\mu C$ charge is placed inside the closed surface, then the flux passing through the surface is _____.

(A) 4φ (B) φ (C) 2φ (D) zero   **[GUJCET 2018]**

5. Four closed surfaces and corresponding charge distributions are shown below:

Let the respective electric fluxes through the surfaces be Φ_1, Φ_2, Φ_3 and Φ_4, then :

(A) $\Phi_1 = \Phi_2 = \Phi_3 = \Phi_4$ (B) $\Phi_1 > \Phi_3 ; \Phi_2 > \Phi_4$ (C) $\Phi_1 > \Phi_2 > \Phi_3 > \Phi_4$ (D) $\Phi_1 < \Phi_2 = \Phi_3 > \Phi_4$

[JEE Main 2017 Online]

6. Arrangement of charges are shown in the figure. Flux linked with the closed surface P and Q respectively are _____ and _____.
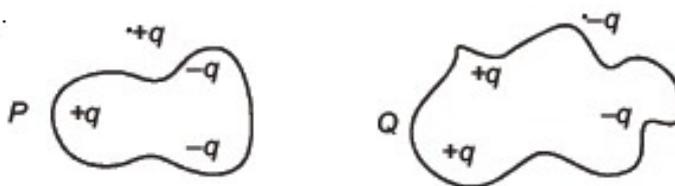
(A) Zero, Zero   (B) $\dfrac{q}{\in_0}, \dfrac{-q}{\in_0}$ (C) $\dfrac{-q}{\in_0}, \dfrac{q}{\in_0}$ (D) $\dfrac{q}{\in_0}$, Zero   **[GUJCET 2017]**

1.14 APPLICATION OF GAUSS'S LAW

⇒ **1.14.1 Field due to an infinitely long straight uniformly charged wire**

• Consider an infinitely long thin straight wire with uniform linear charge density λ.

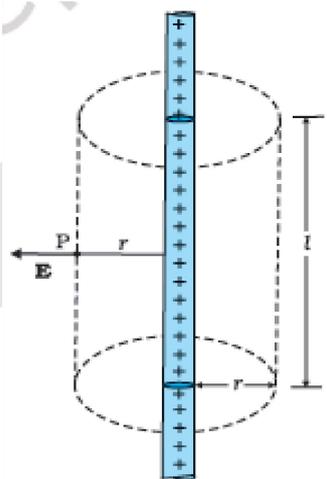• As length of the wire is infinite, the electric field is radial in the plane cutting the wire normally and its magnitude depends only on the radial distance r.

• To calculate the field, imagine a cylindrical Gaussian surface as shown in figure.

• Since the field is radial everywhere, flux through the two ends of the cylindrial Gaussian surface is zero.

• At the cylindrical part of the surface, $\vec{E}$ is normal to the surface at every point, and its magnitude is constant, since it depends on r.

• The surface area of the curved part is $2\pi r l$, where l is the length of the cylinder.

• Flux through the Gaussian surface

     = flux through the curved cylindrical part of the surface

     = $E \times 2\pi r l$

• The Gaussian surface includes charge = λl.

• From Gauss's law, $E \times 2\pi r l = \dfrac{\lambda l}{\in_0}$ or $E = \dfrac{\lambda}{2\pi \in_0 r}$

In vector form, $\vec{E}$ at any point is $\vec{E} = \dfrac{\lambda}{2\pi \in_0 r}\hat{n}$.

where $\hat{n}$ is the radial unit vector in the plane normal to the wire passing through the point.

• $\vec{E}$ is directed outward if λ is positive and inward if λ is negative.

....**QUESTIONS from CBSE Board Exams..**..

Q. 1.

(a) Use Gauss' law to derive the expression for the electric field $\vec{E}$ due to a straight uniformly charged infinite line of charge density λ C/m.

(b) Draw a graph to show the variation of E with perpendicular distance r from the line of charge.

(c) Find the work done in bringing a charge q from perpendicular distance r_1 to r_2 ($r_2 > r_1$).

[5 marks, CBSE 2018]

Q. 2. Using Gauss' law, derive an expression for the electric field at a point near an infinitely long straight uniformly charged wire. **[3 marks, CBSE 2019]**

Q. 3. A long charged cylinder of linear charge density $+\lambda_1$ is surrounded by a hollow coaxial conducting cylinder of linear charge density $-\lambda_2$. Use Gauss's law to obtain expressions for the electric field at a point (i) in the space between the cylinders, and (ii) outside the larger cylinder. **[3 marks, CBSE 2017]**

Q. 4. State Gauss's law in electrostatics. Derive an expression for the electric field due to an infinitely long straight uniformly charged wire. **[3 marks, CBSE 2017]**

....QUESTIONS from GSEB Board Exams..

Q. 1. Derive an expression for the electric field due to an infinitely long straight uniformly charged wire. **[3 marks, GSEB 2022]**

..............................NCERT based QUESTIONS from Competitive Exams.....................................

1. An infinite line charge produces a field of $9 \times 10^4 \ NC^{-1}$ at a distance of $2 \ cm$. Calculate electrical field produced at a distance of $3 \ cm$.

(A)$-6 \times 10^4 \ NC^{-1}$ (B)$6 \times 10^{-5} \ NC^{-1}$ (C)$6 \times 10^3 \ NC^{-1}$ (D)$6 \times 10^2 \ NC^{-1}$ **[GUJCET 2022]**

2. Two parallel infinite line charges with linear charge densities $+\lambda$ C/m and $-\lambda$ C/m are placed at a distance of $2R$ in free space. What is the electric field mid-way between the two line charges ?

(A)Zero (B)$\dfrac{2\lambda}{\pi \in_0 R}$ N/C (C)$\dfrac{\lambda}{\pi \in_0 R}$ N/C (D)$\dfrac{\lambda}{2\pi \in_0 R}$ N/C **[NEET 2019]**

....

$\Rightarrow$ **1.14.2 Field due to uniformly charged plane sheet**

● Let σ be the uniform surface charge density of an infinite plane sheet.

● The x-axis is taken normal to given plane.The electric field will not depend on y and z coordiantes and its direction at every point must be parallel to the x-direction.

● Consider the Gaussian surface to be a rectangular parallelopiped (a cylindrical surface can also be taken) of cross sectional area A as shown in figure.

Surface charge density σ
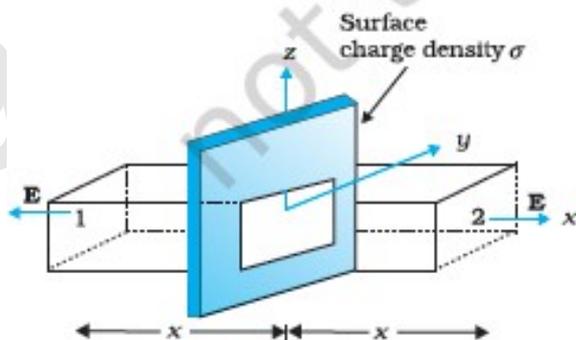
OR
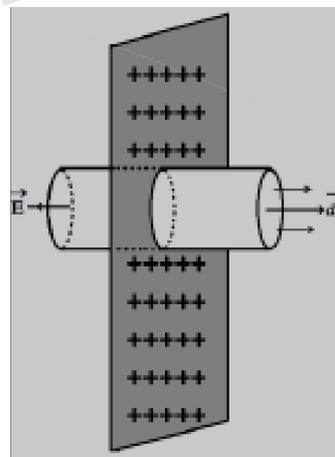
● Only two faces 1 and 2 will contribute to the flux as electric field lines are parallel to the other faces and therefore they they do not contribute to the total flux.

- The unit vector normal to surface 1 is in $-x$ direction while the unit vector normal to surface 2 is in the $+x$ direction.Therefore, the flux $\vec{E} . \Delta \vec{S}$ through both the surfaces are equal and add up. Thus the net flux through the Gaussian surface is $2EA$.

- The charge enclosed by the closed surface is σA.

- By Gauss's law, $2EA = \dfrac{\sigma A}{\in_0}$ or $E = \dfrac{\sigma}{2 \in_0}$.

- In vector form, $\vec{E} = \dfrac{\sigma}{2 \in_0} \hat{n}$

   where $\hat{n}$ is a unit vector normal to the plane and going away from it.

- $\vec{E}$ is directed away from the plate if σ is positive and toward the plate if σ is negative.

NOTE: E *is independent of* x.

....**QUESTIONS from CBSE Board Exams..**...

Q. 1. Two large charged plane sheets of charge densities σ and -2σ C/m^2 are arranged vertically with a separation of d between them. Deduce expressions for the electric field at points (i) to the left of the first sheet, (ii) to the right of the second sheet, and (iii) between the two sheets.
[3 marks, CBSE 2019]

Q. 2. Two large parallel plane sheets have uniform charge densities $+\sigma$ and $-\sigma$. Determine the electric field (i) between the sheets, and (ii) outside the sheets. **[2 marks, CBSE 2019]**

Q. 3.
 (a) Use Gauss's theorem to find the electric field due to a uniformly charged infinitely large plane thin sheet with surface charge density σ.
 (b) An infinitely large thin plane sheet has a uniform surface charge density $+\sigma$.Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distant r, in front of the charged plane sheet. **[5 marks, CBSE 2017]**

....**NCERT based QUESTIONS from Competitive Exams**...

1. The charge density of uniformly charged infinite plane is σ. A simple pendulum is suspended vertically downward near it. Charge q_0 is placed on metallic bob. If the angle made by the string is θ with vertical direction then ...

(A) $\sigma \propto \dfrac{\tan \theta}{q_0}$ (B) $\sigma \propto \dfrac{\cot \theta}{q_0}$ (C) $\sigma \propto \tan \theta$ (D) $\sigma \propto \dfrac{q_0}{\tan \theta}$ **[GUJCET 2020]**

2. Electric field intensity at points in between and outside two thin separated parallel sheets of infinite dimen sion with like charges of same surface charge density (σ) are _____ and _____ respectively.

(A) $\dfrac{\sigma}{\in_0} , \dfrac{\sigma}{\in_0}$ (B) $0 , \dfrac{\sigma}{\in_0}$ (C) $0, 0$ (D) $\dfrac{\sigma}{\in_0} , 0$ **[GUJCET 2017]**

....

⇒ **1.14.3 Field due to a uniformly charged thin spherical shell**

● Let σ be the uniform surface charge density of a thin spherical shell of radius R.

⇒ **Field outside the shell $(r > R)$:**

● Consider a point P outside the shell with radius vector $\vec{r}$.
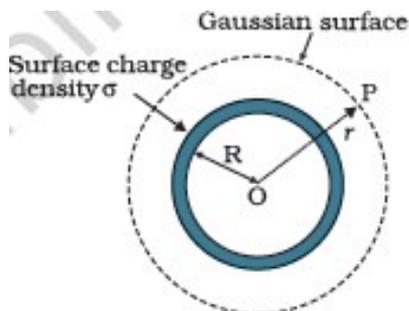
● To calculate $\vec{E}$ at P, consider a spherical Gaussian surface of radius r and with centre O, passing through P.

● The electric field at each point of the Gaussian surface has the same magnitude E and is along the radius vector at each point. Thus, $\vec{E}$ and $\Delta \vec{S}$ at every point are parallel and the flux through the Gaussian surface is $E\,\Delta S$.

● Summing over all ΔS, the flux through the Gaussian surface is $E \times 4\pi r^2$.

● The charge enclosed is $\sigma \times 4\pi R^2$.

● By Gauss's law,

$$E \times 4\pi r^2 = \frac{\sigma}{\epsilon_0} 4\pi R^2$$

or

$$E = \frac{\sigma R^2}{\epsilon_0 \, r^2} = \frac{q}{4\pi \epsilon_0 \, r^2}$$

where $q = 4\pi R^2 \sigma$ is the total charge on the spherical shell.

● In vector form, $\vec{E} = \dfrac{q}{4\pi \epsilon_0 \, r^2} \hat{r}$

● The electric field is directed outward if $q > 0$ and inward if $q < 0$.

● This electric field is exactly the field produced by a charge q placed at the centre O. Thus for points outside the shell, the field due to a uniformly charged shell is as if the entire charge of the shell is concentrated at its centre.

⇒ **Field inside the shell $(r < R)$:**

● Consider a point P inside the shell with radius vector $\vec{r}$.
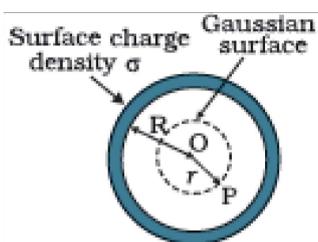
- The Gaussian surface is a sphere through P centred at O.

- The flux through the Gaussian surface is $E \times 4\pi r^2$.
- Here the Gaussian surface encloses no charge.

- From Gauss's law, $E \times 4\pi r^2 = 0$ i.e. $E = 0$

The **field due to a uniformly charged thin shell is zero at all points inside the shell**.

....QUESTIONS from CBSE Board Exams..

Q. 1. The magnitude of electric field due to a point charge $2q$, at distance r is E. Then the magnitude of electric field due to a uniformly charged thin spherical shell of radius R with total charge q at a distance

$\dfrac{r}{2} (r >> R)$ will be:

(A) $\dfrac{E}{4}$ (B) 0 (C) $2E$ (D) $4E$ **[1 mark, CBSE 2021(I)]**

Q. 2.

(a) Using Gauss law, derive expression for electric field due to a spherical shell of uniform charge distribution σ and radius R at a point lying at a distance x from the centre of shell, such that

  (i) $0 < x < R$, and   (ii) $x > R$

(b) An electric field is uniform and acts along $+x$ direction in the region of positive x. It is also uniform with the same magnitude but acts in $-x$ direction in the region of negative x. The value of the field is $E = 200 \, N/C$ for $x > 0$ and $E = -200 \, N/C$ for $x < 0$. A right circular cylinder of length $20 \, cm$ and radius $5 \, cm$ has its centre at the origin and its axis along the x-axis so that one flat face is at $x = +10 \, cm$ and the other is at $x = -10 \, cm$. Find:

  (i) The net outward flux through the cylinder.   (ii) The net charge present inside the cylinder.

[5 marks, CBSE 2020]

Q. 3. A spherical conducting shell of inner radius r_1 and outer radius r_2 has a charge Q.

(a) A charge q is placed at the centre of the shell. Find out the surface charge density on the inner and outer surfaces of the wall.

(b) Is the electric field inside a cavity (with no charge) zero; independent of the fact whether the shell is sphericall or not ? Explain.   **[3 marks, CBSE 2019]**

Q. 4. A metallic spherical shell has an inner radius R_1 and outer radius R_2. A charge Q is placed at the centre of the shell. What will be the surface charge density on the (i) inner surface, and (ii) outer surface of the shell?

[1 mark, CBSE 2019]

Q. 5. Apply Gauss's law to show that for a charged spherical shell, the electric field outside the sehll is, as if the entire charge were concentrated at the centre.   **[2 marks, CBSE 2019]**

Q. 6.

(a) Using Gauss' law, obtain expressions for the electric field (i) inside, and (ii) outside a positively charged spherical shell.

(b) Show graphically variation of the electric field as a function of the distance r from the centre of the sphere.

(c) A square plane sheet of side $10 \, cm$ is inclined at an angle of 30^0 with the direction of a uniform electric field of $200 \, NC^{-1}$. Calculate the electric flux passing through the sheet.   **[5 marks, CBSE 2019]**

................................**NCERT based QUESTIONS from Competitive Exams**................................

1. A spherical conductor of radius $10\,cm$ has a charge of $3.2 \times 10^{-7}\,C$ distributed uniformly. What is the magnitude of electric field at a point $15\,cm$ from the centre of the sphere ?

(A) $1.28 \times 10^6\ N/C$ (B) $1.28 \times 10^7\ N/C$

(C) $1.28 \times 10^4\ N/C$ (D) $1.28 \times 10^5\ N/C$ **[NEET 2020]**

2. A hollow metal sphere of radius R is uniformly charged. The electric field due to the sphere at a distance r from the centre

(A) Increases as r increases for $r < R$ and for $r > R$.

(B) Zero as r increases for $r < R$, decreases as r increases for $r > R$.

(C) Zero as r increases for $r < R$, increases as r increases for $r > R$.

(D) Decreases as r increases for $r < R$ and for $r > R$.   **[NEET 2019]**

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My HOMEWORK is my strength