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## Second Unit / Electric Fields and Gauss's Law

The electric field is denoted by the symbol ( $\vec{E}$ ) and is measured in units (N / C).

The electric field is a vector quantity calculated from the relationship: 
$$\vec{E}(\vec{r}) = \frac{\vec{F}(\vec{r})}{q}$$

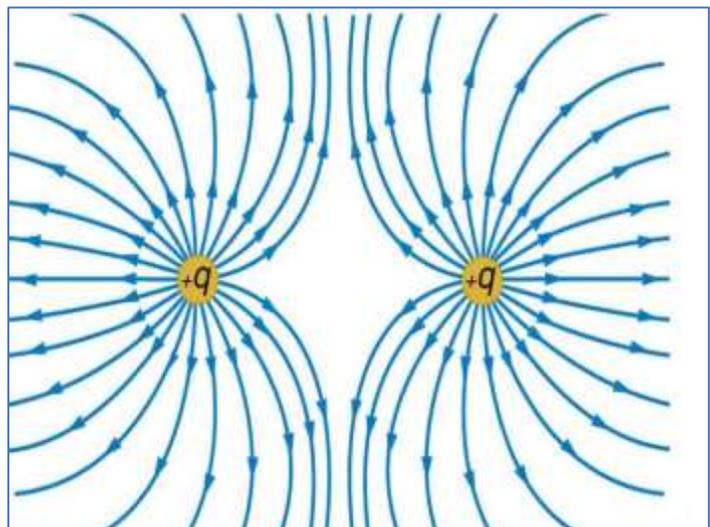
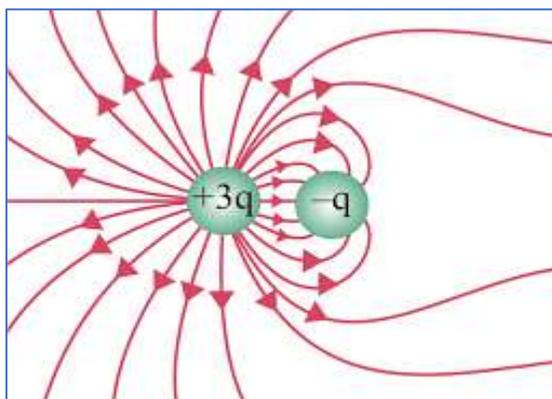
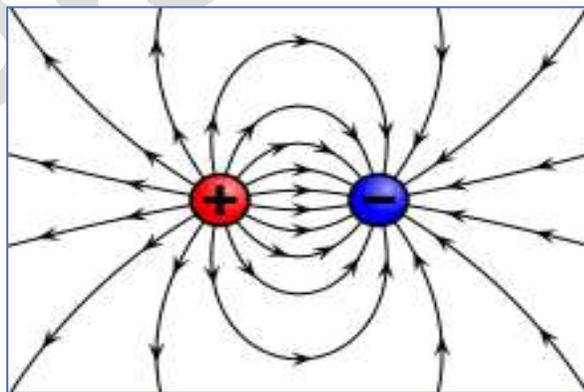
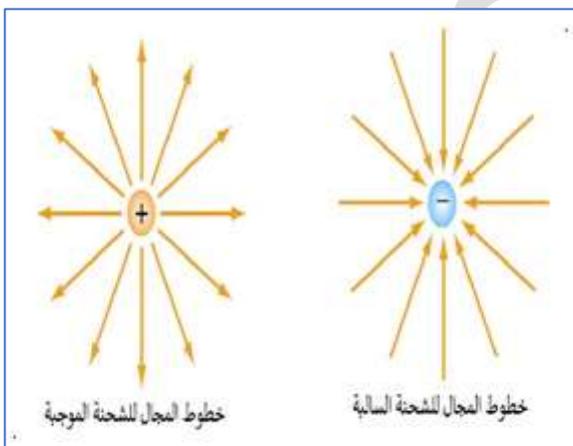
In the case of multiple sources of electric fields at the same time, such as point charges, the electric field is calculated at any given point by overlapping the electric fields resulting from all these sources.

$$\vec{E}_t(\vec{r}) = \vec{E}_1(\vec{r}) + \vec{E}_2(\vec{r}) + \dots + \vec{E}_n(\vec{r})$$

**Electric field lines:** - Graphically represent the sum of the vector force exerted on a positive test charge unit.

Font characteristics:

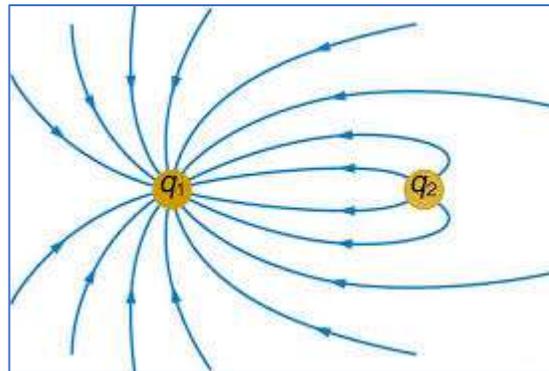
- arises from positive charges and ends in negative charges.
- Do not intersect. Because its intersection at a point means that the force obtained will be in opposite directions at the same point, which is impossible.
- The density of the lines is directly proportional to the amount of force as well as the amount of charge.
- The direction of the field line at the point is the same as the direction of the force at that point.



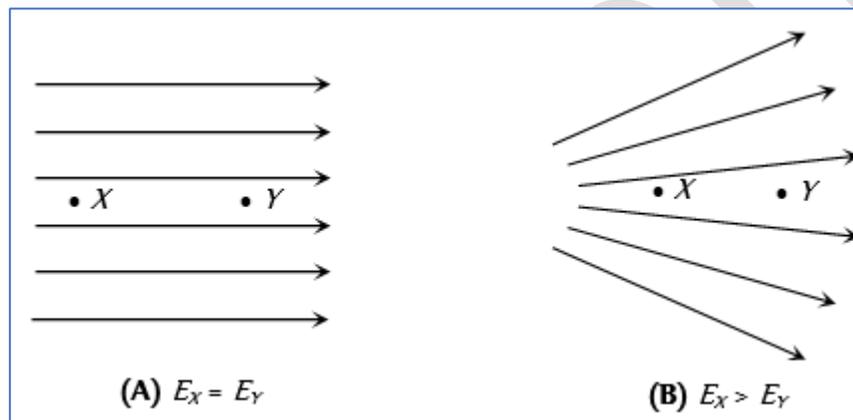
**Computational skill:** - In the form attached aside: -

- Select the type of charges  $q_1$  and  $q_2$ .

- If  $q_1 = 100\mu\text{C}$ , what is  $q_2$ ?



**Very important clarification:** - Look at the two figures attached.

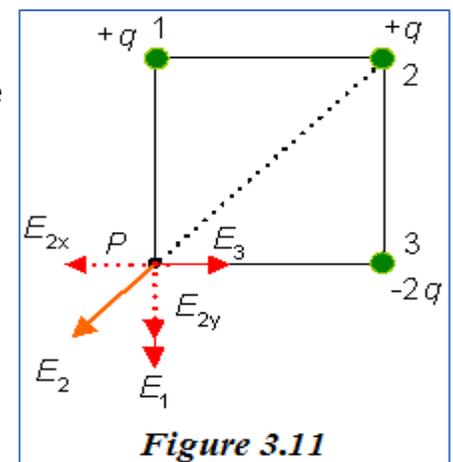


Electric field resulting from point charges Calculated from the relationship: -

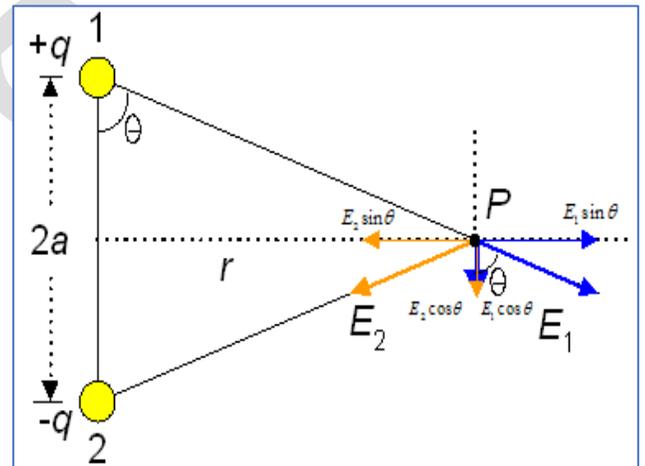
$$E = \frac{F}{q_0} = \frac{1}{4\pi\epsilon_0} \frac{|q|}{r^2}$$

**Disclaimer:** - Do not forget that the electric field is a vector quantity must analyze each amount of it into two components and then combine the components on the same axis together and find the final outcome of the application of the relationship Pythagoras.

**Example 1:** - In the figure shown in front of you if it is ( $q = 60\mu\text{C}$ ) where three Point charges are located on three square ends of the rib length (10Cm). Calculate The amount and direction of the total electric field influencing point (P).



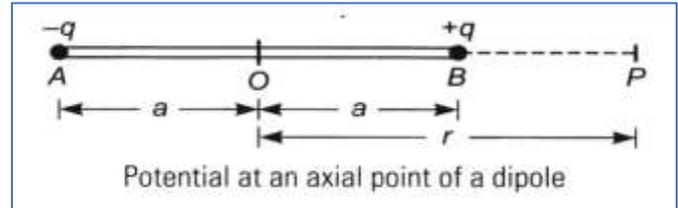
**Example 2:** - Study the adjacent figure and through your understanding of the analysis, calculate the amount and direction of the total electric field at point (P).



**The electric field produced by the dipole Bipolar:** - A system of two particles charged with two charges equal in size and different in type.

Using the overlay principle can calculate the electric field

Arising from the charges at point (P) located on Stretch the axis between them.



$$\vec{E} = \vec{E}_A + \vec{E}_B$$

$$E = kq \left( \frac{1}{(r-a)^2} - \frac{1}{(r+a)^2} \right) \text{ And to break the equation mathematically be: -}$$

$$E = kq \left( \frac{(r+a)^2 - (r-a)^2}{(r-a)^2 (r+a)^2} \right)$$

Then we unscrew the brackets to become the shape is: -

$$E = kq \left( \frac{r^2 + 2ar + a^2 - r^2 + 2ar - a^2}{(r-a)^2 (r+a)^2} \right) \text{ and then :-}$$

$$E = kq \left( \frac{4ar}{(r^2 - a^2)^2} \right)$$

If we consider that (  $d = 2a, x = r, x \gg d$  ) then we arrive to :-

$$E = kq \left( \frac{2dx}{\left(x^2 - \left(\frac{d}{2}\right)^2\right)^2} \right)$$

Where the torque of the dipole is given from the following relationship: -  $p = qd$

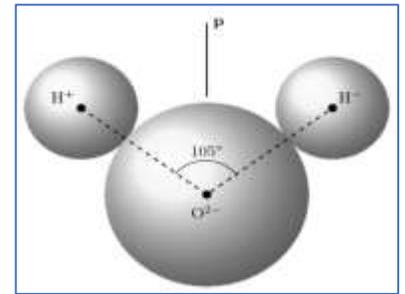
Thus, the field will be approximately equal to the amount:

$$E = \frac{2kp}{x^3}$$

It is the amount of electric field produced by the dipole along the positive (x) axis at a distance that is large compared to the distance between the two charges.

**Water molecule :-**

Each water molecule consists of two cycles of hydrogen and an oxygen cycle as is Shown aside. So that the three atoms are arranged so that the two lines are made Its amount is (105°). See Figure.



**Skill:** - Calculate the dipole moment of the water molecule

Note that the distance between hydrogen atom and oxygen atom = 10<sup>-10</sup>m? (Consider the positive charge center in the middle Distance between the two oxygen centers)

**General distributions of the charges**

We have already seen how we calculated the electric field for three point charges and how much effort we change in calculating the result using the overlay principle. If we follow this method of calculating the field for millions or trillions of point charges, we would not be able to use whatever mathematical equations and techniques such as computer and others.

Here there is a need to use the science of integration in solving these problems in an easy and simple way, especially for the charge distributed regularly on the regular objects in one dimension (wire for example) and in two dimensions (metal plate) and also in three dimensions (metal ball)

For a one-dimensional object, the charge distribution along the line is: **dq = λdx**, λ: longitudinal charge density

For a 2D object the charge distribution on the surface is: **dq = σdA**, σ: surface charge density

For a three-dimensional object, the charge distribution on the volume is: **dq = ρdv**, ρ: the volume charge density

The amount of electric field resulting from the differential charge distribution is therefore:  $dE = K \frac{dq}{r^2}$

**Charges on a straight wire( finite line of charge )**

Example: - Calculate the electric field resulting from a wire whose length (2a) is at a point along a line that equals it. Note that the density of its linear charge (λ).

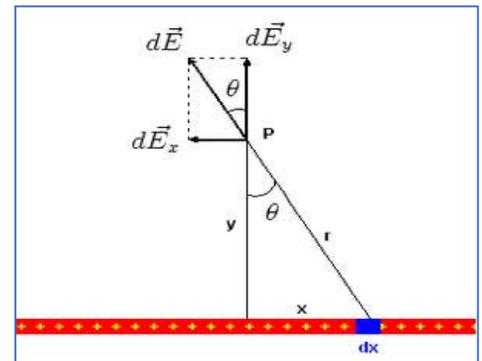
Solution: - The differential charge is on the xaxis .When we find

The amount of the electric field at the point (0, y) is equal to  $dE_y = k \frac{dq}{r^2} \cos \theta$

Accordingly: -

The amount of the total field generated by the length of the whole wire is:

$$= 2 \int_0^a k \frac{dq}{r^2} \cos \theta = 2k \int_0^a \frac{\lambda dx}{r^2} \frac{y}{r} E_y = 2 \int_0^a dE_y$$



In the order of boundaries and variables are:  $E_y = 2k\lambda y \int_0^a \frac{dx}{(x^2 + y^2)^{3/2}} = 2k\lambda y \frac{1}{y^2} \frac{a}{\sqrt{(y^2 + a^2)}}$

With the abbreviations are:  $E_y = \frac{2k\lambda a}{y\sqrt{(y^2 + a^2)}}$

This is the value of the electric field at a distance (y) on a line that is half the wire.

If the length of the wire is infinite, the field at the same distance becomes equal to the amount:  $E_y = \frac{2k\lambda}{y}$

In the sense that the electric field is inversely proportional to the distance from the wire .

**Ring of charge**

Calculate the electric field at the point ( $x = b$ ). Note that the radius of the ring =  $a$  and The ring has a regular linear charge density.

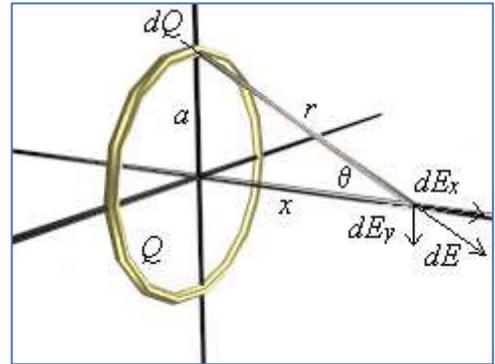
Solution: - Due to the uniform distribution of charges, the integration of vertical field components

On the axis of the ring = zero. Because the electric fields of the charge elements are on

The two sides cancel each other out. (See Figure)

Thus, only the actual field is the result of parallel field components

For ring axis only.



$$\text{The shape aside is: } -dE_x = k \frac{dq}{r^2} \cos \theta = k \frac{dq}{r^2} \frac{b}{r} = kb \frac{dq}{r^3} \implies E_x = \int_{\text{ring}} dE_x = \int_{\text{ring}} \frac{b}{r} k \frac{dq}{r^2}$$

To integrate, we need to connect the differential charge to the circumference of the ring ( $2\pi a$ ) where:

$$dq = \frac{Q}{2\pi a} ds \quad \text{and then Compensated by integration, we write: } E_x = \int_0^{2\pi a} k \left( \frac{Q}{2\pi a} ds \right) \frac{b}{r^3}$$

$$\text{We then integrate after the fixed boundary output } E_x = \frac{kQb}{2\pi a r^3} \int_0^{2\pi a} ds = \frac{kQb}{2\pi a r^3} (2\pi a) = \frac{kQb}{r^3}$$

$$\text{With compensation, the value of the field becomes: } E_x = \frac{kQb}{(a^2 + b^2)^{3/2}} \quad \text{if we write ( } a=R \text{ ) then :}$$

$$E_x = \frac{kQb}{(R^2 + b^2)^{3/2}}$$

$$\text{IF ( } b \gg R \text{ ) the field becomes: } E_x = \frac{kQ}{b^2}$$

$$\text{If ( } b = 0 \text{ ) the field will be: } E_x = 0$$

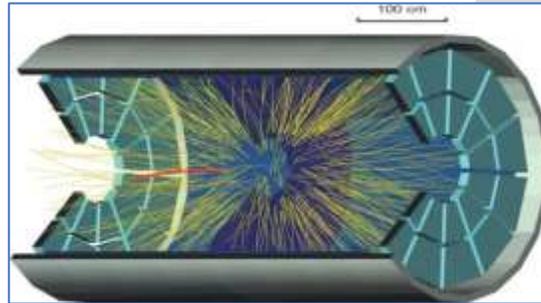
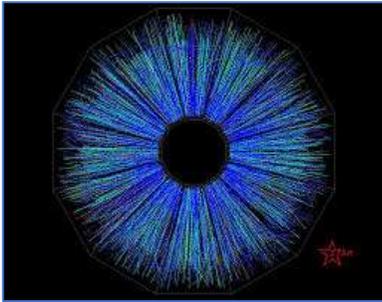
### **The force of an electric field**

The force of a charge placed in the electric field can be calculated by the relation ( $\vec{F} = q\vec{E}$ ) in the same direction of the field if the charge is positive, and the direction of force is opposite to the direction of the electric field if the charge is negative .

### **Time projection compartment**

It is a collision chamber between the gold atoms at very high energies. These collisions result in many particles flowing away from the reaction point at high speeds.

There is a room like this (STAR TPC) at Brookhaven Laboratory in New York.



### **The movement of an electron over a charged board**

An electron unleashed its kinetic energy (2KeV) over a conductive board, if the surface charge density of the board is  $4 \times 10^{-6} \text{C/m}^2$ . If the electron path is in the positive direction of the x-axis above the board. Calculate the vertical deviation of the electron after it crosses a horizontal distance of (4Cm)?

**Dipole in the electric field**

It is known that the positive charge is affected by electric force towards the field and the negative charge in opposite behavior .(See Figure)

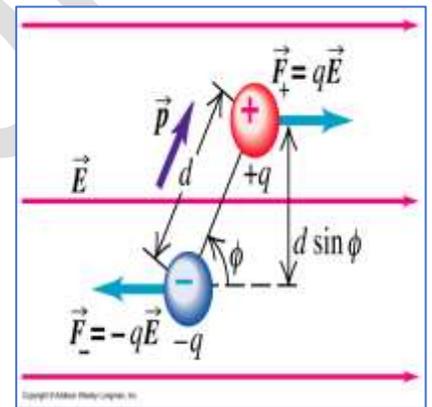
Torque is given in a dipole under the influence of External Electrician  $\vec{\tau} = \vec{F} \times \vec{r} = qEd \sin \theta$

Since:  $p = qd$

Then the torque becomes:  $\tau = pE \sin \theta \Rightarrow \vec{\tau} = \vec{p} \times \vec{E}$

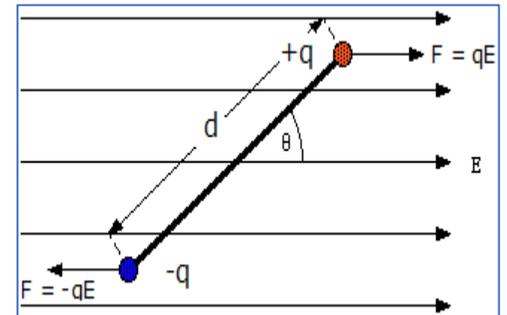
**The right hand base** of the directional multiplication of the dipole torque determines the direction of rotation of the dipole so that:

The index finger indicates the direction of the field ( $\vec{E}$ ), the thumb indicates the torque( $\vec{P}$ ) and the middle finger indicates the direction of The product of directional multiplication ( $\vec{\tau}$ ) is perpendicular to both boundaries .



**Example:** - In the attached figure you have. dipole with moment ( $p=1.4 \times 10^{-12} \text{C.m}$ ) in a uniform electric field of ( $500 \text{N / C}$ ) And so that the angle at a certain moment ( $\theta = 37^\circ$ ).

- Calculate the amount of torque of the dipole at this moment



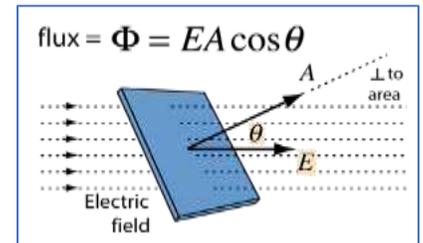
- Express Cartesian torque components at this moment.

- Determine the direction of torque of the dipole .

**Electric Flux**

An electric field that passes through a given area (A), and is directly proportional to the number of field lines passing through the area.

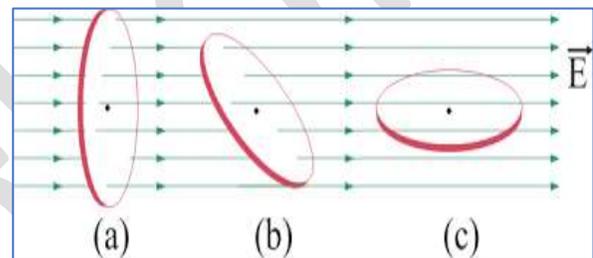
We get the flow through the equation: -  $\phi = EA \cos \theta$



Where ( $\theta$ ) is the angle between the field direction and the area vector (perpendicular to the surface).

We get the flux in the case of the closed surface through the following formula: -  $\phi = \oiint \vec{E} \cdot d\vec{A}$

Question: - Arrange the values of the electric flux that passes the loop in its three shown positions As attached.



**Electric flux through a cube**

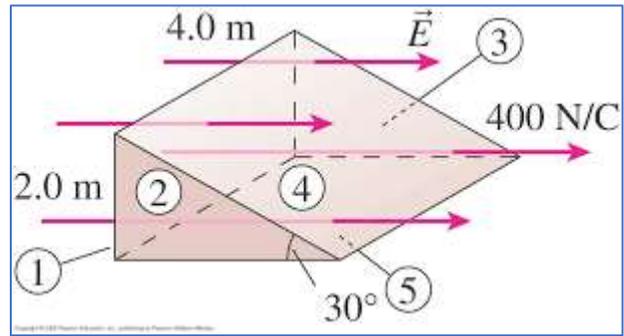
Note that the flux through parallel surfaces For field = zero because ( $\theta = 90^\circ$ ).  
Notice that the area vector is always Point vertically on the surface towards the outside

**Example: Electric Flux through a Cube**

E along x-axis:  
To find the net electric flux.

1	2	3	4	5	6
$\Phi_E = -E l^2$	$+E l^2$	$+0$	$+0$	$+0$	$+0 = 0$

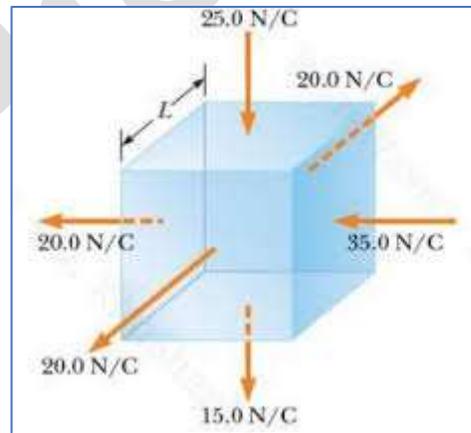
**Question:** -in the prism shown aside, find the electric flux through lateral surface (4).



**Question:** - In drawing the attached cube ( $L = 20\text{cm}$ ).

- Calculate the amount of electrical flux that crosses the six surfaces of the cube

- Does the cube have a charge inside it? What type?



- Calculate the amount of charge inside the cube

**Note:** - When there is a charge inside the Gaussian surface, the electric field lines will appear to flow inside or outside the surface. When there is no charge inside the surface, the sum of the electric field lines flowing in or out of the surface will be zero.

These observations and the definition of electric flux which quantifies the concept of the flow of the electric field

lines , lead to **Gauss's law** :

$$\phi = \frac{q_{in}}{\epsilon_o}$$

**Question :-** four charges are placed in three – dimensional space . the charges have magnitudes +3q , -q , +2q , -7q . if a Gaussian surface encloses all the charges , what will be the electric flux through the surface ?

**Question :-**

**22.47** The six faces of a cubical box each measure 20.0 cm by 20 cm, and the faces are numbered such that faces 1 and 6 are opposite to each other, as are faces 2 and 5, and faces 3 and 4. The flux through each face is:

Face	Flux (N m <sup>2</sup> /C)
1	-70.0
2	-300.0
3	-300.0
4	+300.0
5	-400.0
6	-500.0

Find the net charge inside the cube.

## Gauss's Law and Coulomb's Law

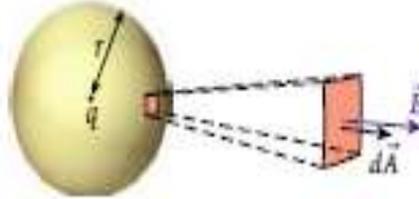
We impose a positive point charge with the direction of the electric field resulting from the charge along the radii to the outside .

We choose a spherical surface with a radius (r) with the charge at its center. This surface is the Gaussian surface.

Looking at the attached figure we see that the field intersects each differential element of the surface of the Gaussian spherical shape, so that the field vector is parallel to the surface area vector always moving away from the Gaussian spherical surface.

Calculates the flow of the relationship: -

$$\Phi = \iint \vec{E} \cdot d\vec{A} = \iint E dA.$$



Because the field has the same amount anywhere in the space at the distance (r) of the point charge (q), the field can be output (E) of the limits of integration .

Accordingly: -

$$\Phi = \iint E dA = E \iint dA.$$

Calculating the differential surface area on the spherical surface is:

$$\Phi = (E) \left( \iint dA \right) = \left( \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \right) (4\pi r^2) = \frac{q}{\epsilon_0},$$

This proves the validity of Gauss's law through Coulomb's law .

## shielding

- The electrostatic field inside any insulated conductor is always zero.
- The cavities inside the conductors are protected from electrical fields.

One of the most famous applications of this protection in our daily life (the car), which is originally applied to (Faraday cage) as the car can protect you from lightning bolt when inside, but be vulnerable if the car is exposed and has increased the risk recently when the metal panels were replaced The steel frames surrounding the passenger compartment are made of fiberglass, plastic and carbon fiber.

## Special cases in the uniformity of distribution of electric charges

We will calculate the electric field resulting from charged objects with different geometric shapes such as the cylinder, flat surface and sphere .

**First: - cylindrical symmetry**

Applying integration on the closed Gaussian surface: -

$$\oiint \vec{E} \cdot d\vec{A} = EA = E(2\pi rL) = \frac{q}{\epsilon_0} = \frac{\lambda L}{\epsilon_0},$$



Since the Gaussian surface is the lateral surface of the cylinder which has an area of (base circumference X height) that is (  $2\pi rL$  ) and distribution of the charge is longitudinal (  $q = \lambda L$  ) .and after substitution we have :

$$E = \frac{\lambda}{2\pi\epsilon_0 r} = \frac{2k\lambda}{r},$$

**Note that** the field of point charge decreases much faster than the electric field due to the long wire, which decreases in inverse proportion to the distance while in the point charge it decreases inversely with the square of distance .

**22.58** An infinitely long charged wire produces an electric field of magnitude  $1.23 \cdot 10^3 \text{ N/C}$  at a distance of 50.0 cm perpendicular to the wire. The direction of the electric field is toward the wire.

- What is the charge distribution?
- How many electrons per unit length are on the wire?

**Question :-** a long horizontal conducting wire has the charge density (  $\lambda = 2.85 \times 10^{-12} \text{ C/m}$  ) . a proton (  $1.67 \times 10^{-27} \text{ kg}$  ) is placed ( 0.68m ) above the wire and released . what is the magnitude of the initial acceleration of the proton ?

**Second: Surface symmetry**

Imagine a Gaussian surface that surrounds the thin flat plate on both sides (see figure)

The electric field is perpendicular to both ends of the cylinder and parallel to its wall.

Using Gauss's law we get:

$$\oiint \vec{E} \cdot d\vec{A} = (EA + EA) = \frac{q}{\epsilon_0} = \frac{\sigma A}{\epsilon_0},$$

So the amount of electric field resulting from an infinite **nonconducting** (sheet) charge plane would be:

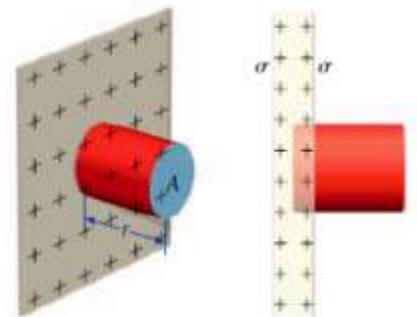
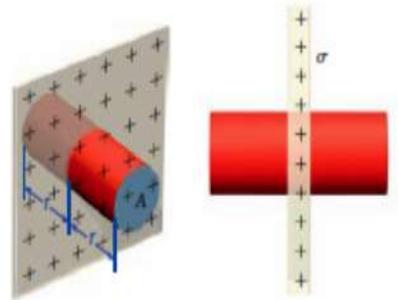
$$E = \frac{\sigma}{2\epsilon_0}.$$

For an infinite conductor plate, its charge density ( $\sigma > 0$ ) on each surface. The flow through the Gaussian surface is (EA), so:

$$\oiint \vec{E} \cdot d\vec{A} = EA = \frac{\sigma A}{\epsilon_0}.$$

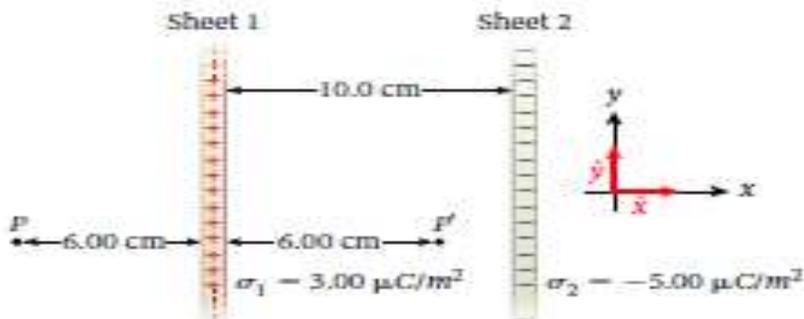
If the amount of electric field outside the surface of the flat **conductor** charged is: -

$$E = \frac{\sigma}{\epsilon_0}.$$



•22.63 Two infinite sheets of charge are separated by 10.0 cm as shown in the figure. Sheet 1 has a surface charge distribution of  $\sigma_1 = 3.00 \mu\text{C}/\text{m}^2$  and sheet 2 has a surface charge distribution of  $\sigma_2 = -5.00 \mu\text{C}/\text{m}^2$ . Find the total electric field (magnitude and direction) at each of the following locations:

- a) at point P, 6.00 cm to the left of sheet 1
- b) at point P' 6.00 cm to the right of sheet 1



**22.76** Two infinite, uniformly charged, flat nonconducting surfaces are mutually perpendicular. One of the surfaces has a charge distribution of  $+30.0 \text{ pC/m}^2$ , and the other has a charge distribution of  $-40.0 \text{ pC/m}^2$ . What is the magnitude of the electric field at any point not on either surface?

**•22.79** An object with mass  $m = 1.0 \text{ g}$  and charge  $q$  is placed at point A, which is  $0.05 \text{ m}$  above an infinitely large, uniformly charged, nonconducting sheet ( $\sigma = -3.5 \cdot 10^{-5} \text{ C/m}^2$ ), as shown in the figure. Gravity is acting downward ( $g = 9.81 \text{ m/s}^2$ ). Determine the number,  $N$ , of electrons that must be added to or removed from the object for the object to remain motionless above the charged plane.



**Third: - Spherical symmetry**

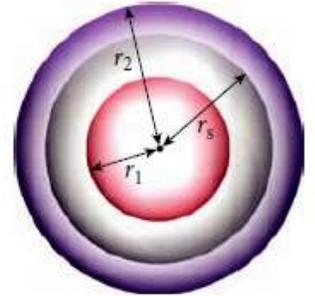
**1. For spherical structure :**

We find the electric field resulting from a uniform spherical distribution of the charge.

In the attached figure aside we use a spherical Gaussian surface ( $r_2 > r_s$ ).

And concentric with a charged

When applying Gaussian law  $\oiint \vec{E} \cdot d\vec{A} = E(4\pi r_2^2) = \frac{q}{\epsilon_0}$ .



By calculating the electric field we find:

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r_2^2}$$

For the internal Gaussian spherical surface ( $r_1 < r_s$ ) in which is concentrated as well as the charged spherical structure we get :-

$$\oiint \vec{E} \cdot d\vec{A} = E(4\pi r_1^2) = 0.$$

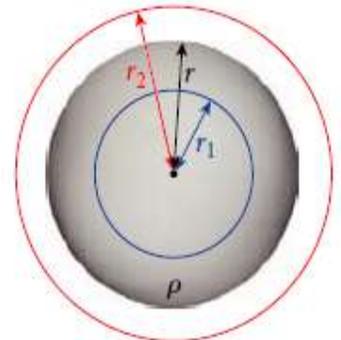
Notice the behavior of the electric field outside the sphere structure as if it were a point charge located at the center of the sphere. Similarly the electric field within the structure = zero.

**2. For uniform volume distribution ( $\rho > 0$ )**

**• At the surface ( $r_1 < r$ ).**

The resulting field of charge is perpendicular to the surface of Gauss and is calculated from the following relationship :-

$$\oiint \vec{E} \cdot d\vec{A} = E(4\pi r_1^2) = \frac{q}{\epsilon_0} = \frac{\rho}{\epsilon_0} \left( \frac{4}{3} \pi r_1^3 \right)$$



The electric field within the charge distribution is therefore:

$$E = \frac{\rho r_1}{3\epsilon_0}$$

The total charge of the sphere can be expressed in  $q_t$ , which is equal to the total volume of the spherical distribution of the charge multiplied by the density of the charge.  $q_t = \rho \frac{4}{3} \pi r^3$ .

And then the amount of charge surrounded by a Gaussian surface is equal to :

$$q = \frac{\text{volume inside } r_1}{\text{volume of charge distribution}} q_t = \frac{\frac{4}{3} \pi r_1^3}{\frac{4}{3} \pi r^3} q_t = \frac{r_1^3}{r^3} q_t$$

Thus we can reformulate Gaussian law for this case as follows:

$$\oiint \vec{E} \cdot d\vec{A} = E(4\pi r_1^2) = \frac{q_t r_1^3}{\epsilon_0 r^3}, \quad \implies \quad E = \frac{q_t r_1}{4\pi\epsilon_0 r^3} = \frac{kq_t r_1}{r^3}$$

• **At the surface ( $r_2 > r$ ).**

Applying Gaussian law:

$$\oiint \vec{E} \cdot d\vec{A} = E(4\pi r_2^2) = \frac{q_t}{\epsilon_0}, \quad \implies E = \frac{q_t}{4\pi\epsilon_0 r_2^2} = \frac{kq_t}{r_2^2}.$$

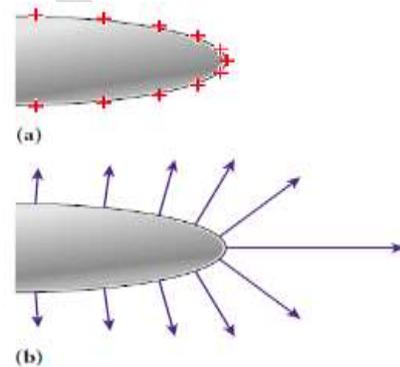
A closer look at the above equations finds that the electric field is similar between the internal distribution of the charge and its external distribution.

**Sharp edges and lightning rods**

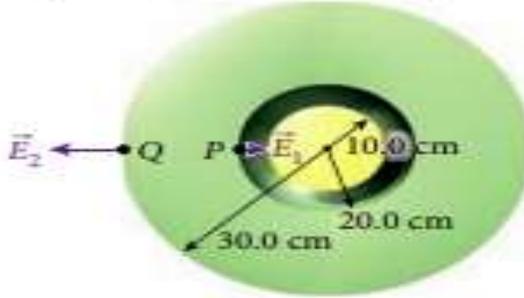
The electric field at the sharp end is as large as possible because the field lines are closer to each other compared to the flat part of the conductor. This is because the sharp part is more curved. See figure aside.

Lightning conductors are designed from circular ends instead of Sharp ends because science has recently found that sharp ends produce a strong electric field were the air ionization work and produce a condition that causes lightning while the circular ends are effective To protect facilities from lightning and do not increase lightning strikes.

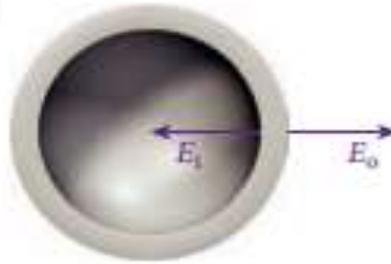
The impedance must be well grounded to carry the charge from the lightning strike away For the facility where the inhibitor is installed.



**22.56** A hollow metal sphere has inner and outer radii of 20.0 cm and 30.0 cm, respectively. As shown in the figure, a solid metal sphere of radius 10.0 cm is located at the center of the hollow sphere. The electric field at a point  $P$ , a distance of 15.0 cm from the center, is found to be  $E_1 = 1.00 \cdot 10^4$  N/C, directed radially inward. At point  $Q$ , a distance of 35.0 cm from the center, the electric field is found to be  $E_2 = 1.00 \cdot 10^4$  N/C, directed radially outward. Determine the total charge on (a) the surface of the inner sphere, (b) the inner surface of the hollow sphere, and (c) the outer surface of the hollow sphere.



•22.52 A hollow conducting spherical shell has an inner radius of 8.00 cm and an outer radius of 10.0 cm. The electric field at the inner surface of the shell,  $E_i$ , has a magnitude of 80.0 N/C and points toward the center of the sphere, and the electric field at the outer surface,  $E_o$ , has a magnitude of 80.0 N/C and points away from the center of the sphere (see the figure). Determine the magnitude of the charge on the inner surface and the outer surface of the spherical shell.



huss.ghe

**22.73** A solid metal sphere of radius 8.00 cm, with a total charge of  $10.0 \mu\text{C}$ , is surrounded by a metallic shell with a radius of 15.0 cm carrying a  $-5.00 \mu\text{C}$  charge. The sphere and the shell are both inside a larger metallic shell of inner radius 20.0 cm and outer radius 24.0 cm. The sphere and the two shells are concentric.

- a) What is the charge on the inner wall of the larger shell?
- b) If the electric field outside the larger shell is zero, what is the charge on the outer wall of the shell?

huss.ghor

•22.59 A solid sphere of radius  $R$  has a nonuniform charge distribution  $\rho = Ar^2$ , where  $A$  is a constant. Determine the total charge,  $Q$ , within the volume of the sphere.

huss.ghon

**•22.61** A sphere centered at the origin has a volume charge distribution of  $120 \text{ nC/cm}^3$  and a radius of  $12 \text{ cm}$ . The sphere is centered inside a conducting spherical shell with an inner radius of  $30.0 \text{ cm}$  and an outer radius of  $50.0 \text{ cm}$ . The charge on the spherical shell is  $-2.0 \text{ mC}$ . What is the magnitude and direction of the electric field at each of the following distances from the origin?

- a) at  $r = 10.0 \text{ cm}$       c) at  $r = 40.0 \text{ cm}$   
b) at  $r = 20.0 \text{ cm}$       d) at  $r = 80.0 \text{ cm}$

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**22.71** An infinitely long, solid cylinder of radius  $R = 9.00$  cm, with a uniform charge per unit of volume of  $\rho = 6.40 \cdot 10^{-8}$  C/m<sup>3</sup>, is centered about the  $y$ -axis. Find the magnitude of the electric field at a radius  $r = 4.00$  cm from the center of this cylinder.

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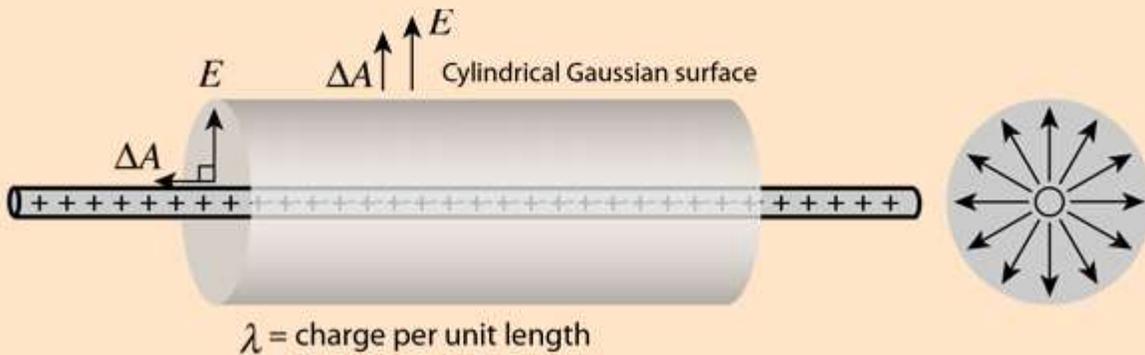
## Electric Field of Line Charge

The [electric field](#) of an infinite line charge with a uniform linear charge density can be obtained by using [Gauss' law](#). Considering a [Gaussian surface](#) in the form of a cylinder at radius  $r$ , the electric field has the same magnitude at every point of the cylinder and is directed outward. The [electric flux](#) is then just the electric field times the area of the cylinder.

$$\Phi = E2\pi rL = \frac{\lambda L}{\epsilon_0}$$

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

This expression is a good approximation for the field close to a long line of charge.



# Electric Field: Conducting Cylinder

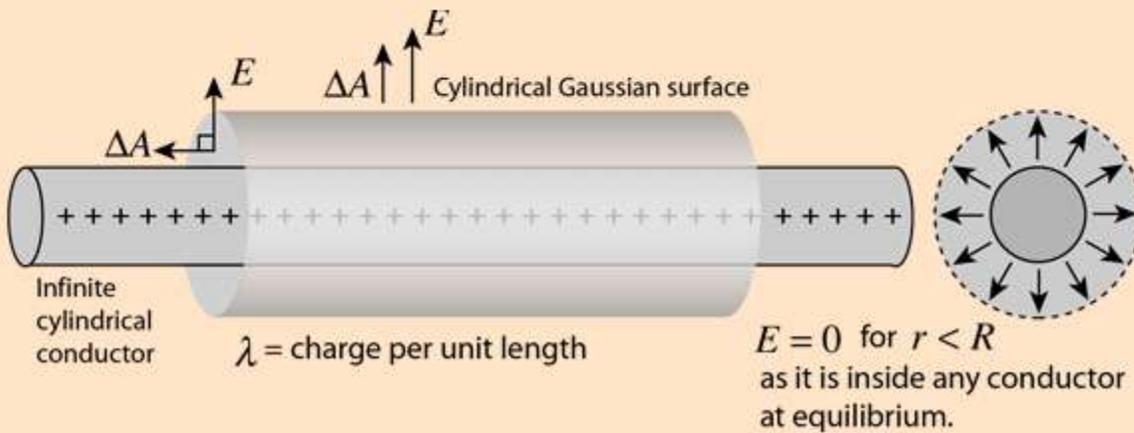
The [electric field](#) of an infinite cylindrical conductor with a uniform linear charge density can be obtained by using [Gauss' law](#). Considering a [Gaussian surface](#) in the form of a cylinder at radius  $r > R$ , the electric field has the same magnitude at every point of the cylinder and is directed outward. The [electric flux](#) is then just the electric field times the area of the cylinder.

$$\Phi = E 2\pi r L = \frac{\lambda L}{\epsilon_0}$$

For  $r \geq R$

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

This expression is a good approximation for the field close to a long conducting cylinder.



## Electric Field: Cylinder of Charge

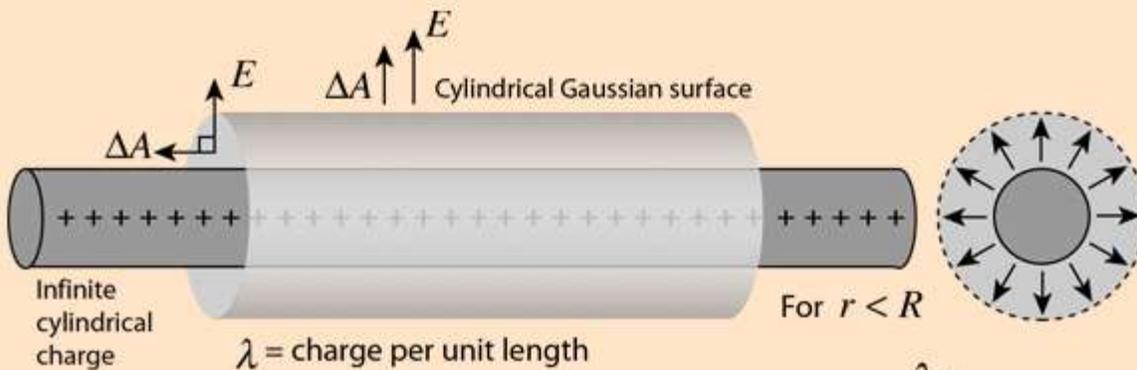
The [electric field](#) of an infinite cylinder of uniform volume charge density can be obtained by using [Gauss' law](#). Considering a [Gaussian surface](#) in the form of a cylinder at radius  $r > R$ , the electric field has the same magnitude at every point of the cylinder and is directed outward. The [electric flux](#) is then just the electric field times the area of the cylinder.

$$\Phi = E2\pi rL = \frac{\lambda L}{\epsilon_0}$$

For  $r \geq R$

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

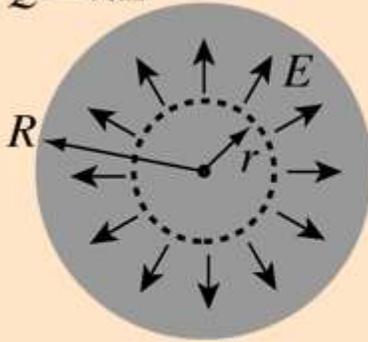
This expression is a good approximation for the field close to a long cylindrical charge.



$$E = \frac{\lambda r}{2\pi\epsilon_0 R^2}$$

## Inside a Cylinder of Charge

$$Q = \lambda L$$



The [electric field](#) inside an infinite cylinder of uniform charge is radially outward (by symmetry), but a cylindrical [Gaussian surface](#) would enclose less than the total charge  $Q$ . The charge inside a radius  $r$  is given by the ratio of the volumes:

$$\frac{Q'}{Q} = \frac{\pi r^2 L}{\pi R^2 L} \quad \text{or} \quad Q' = Q \frac{r^2}{R^2}$$

The [electric flux](#) is then given by  $\Phi = E 2\pi r L = \frac{\lambda L r^2}{\epsilon_0 R^2}$

and the electric field is  $E = \frac{\lambda r}{2\pi\epsilon_0 R^2}$

Note that the limit at  $r=R$  agrees with the expression for  $r \geq R$ .