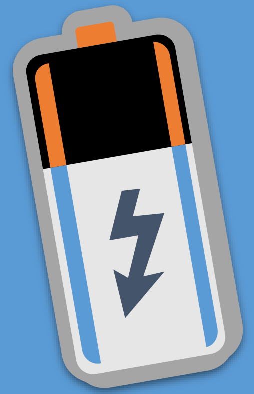
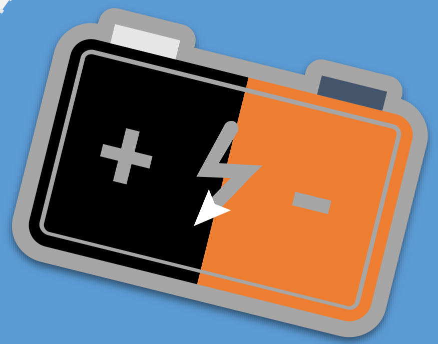
Dr. HARABI



Physics 2

General Electricity

2025 - 2026



Introduction

We are surrounded by devices that depend on the physics of electromagnetism, which is the combination of electric and magnetic phenomena. This physics is at the root of computers, television, radio, telecommunications, household lighting. This physics is also the basis of the natural world, it holds together all the atoms and molecules in the world

The new science of electromagnetism was developed further by workers in many countries. One of the best was Michael Faraday, a truly gifted experimenter with a talent for physical intuition and visualization. That talent is attested to by the fact that his collected laboratory notebooks do not contain a single equation. In the mid-nineteenth century, James Clerk Maxwell put Faraday’s ideas into mathematical form, introduced many new ideas of his own, and put electromagnetism on a sound theoretical basis.

Chapter 1

Electrostatics

Electrostatics

The first chapter is devoted to the study of electrostatic phenomena and Coulomb's Law, electric field , potential and Gauss's theorem. and our first step is to discuss the nature of electric charge and electric force.

1- Electric Charge

Many simple experiments indicate the existence of electric forces and charges. It is possible to impart an electric charge to any solid material by rubbing it with another material. The rubbed solid material is said to be electrified, or electrically charged. For example, a comb becomes electrified when it is used to brush dry hair. This is justified by observing that the comb will attract bits of paper.

Many experiments conducted by Benjamin Franklin reveal that there are two types of electric charges: **positive** and **negative**.

Electrostatics

1- Electric Charge

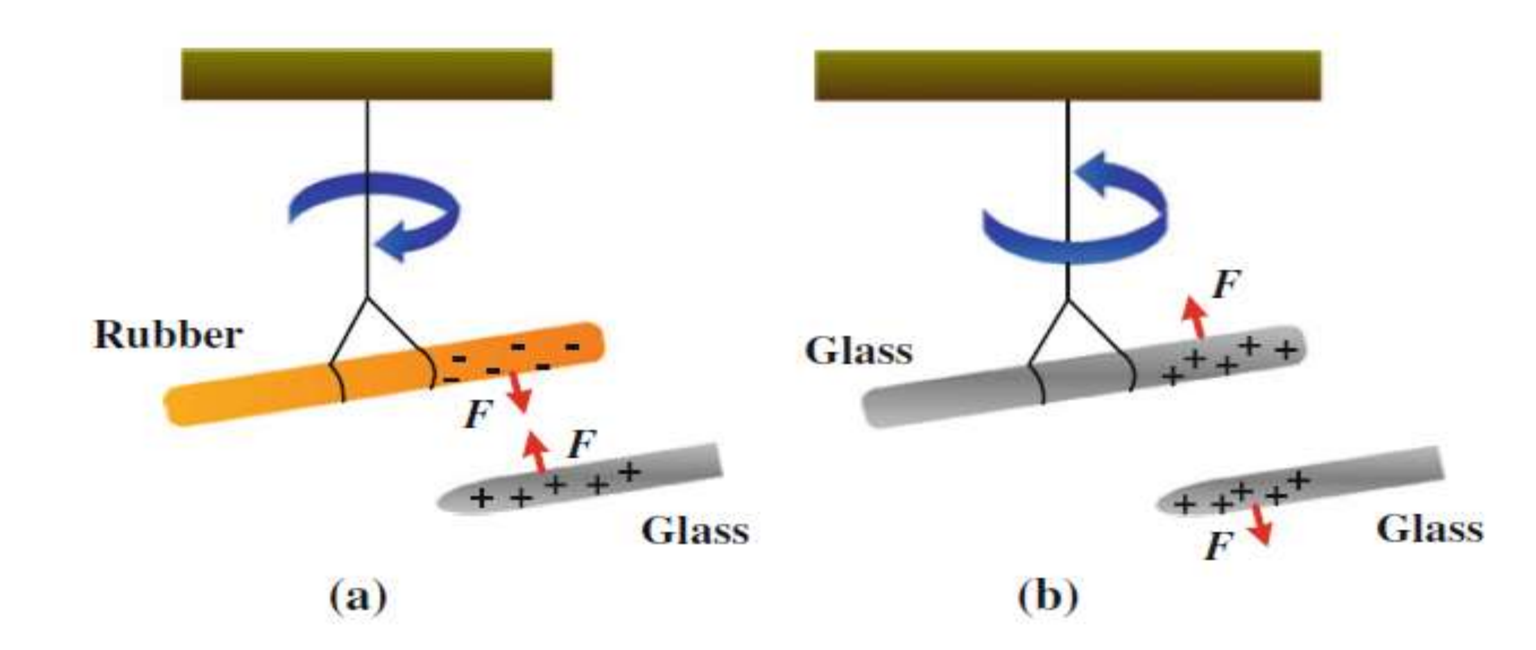


Fig 1

(a) A negatively charged rubber rod attracting a positively charged glass rod.

(b) A positively charged glass rod repelling another positively charged glass rod.

Electrostatics

1- Electric Charge

A glass rod that has been rubbed with silk is commonly used as an example for identifying positive and negative charges. Another common example is a hard rubber rod that has been rubbed with fur. Using Franklin's convention, **positive** charges are formed on a glass rod that has been rubbed with silk, and **negative** charges are formed on a rubber rod that has been rubbed with fur.

When a positively charged glass rod is brought close to a suspended negatively charged rubber rod, the two rods attract each other, see Fig. 1.a. Conversely, if two positively charged glass rods (or two negatively charged rubber rods) are brought close to each other, the two rods repel each other, see Fig. 1.b.

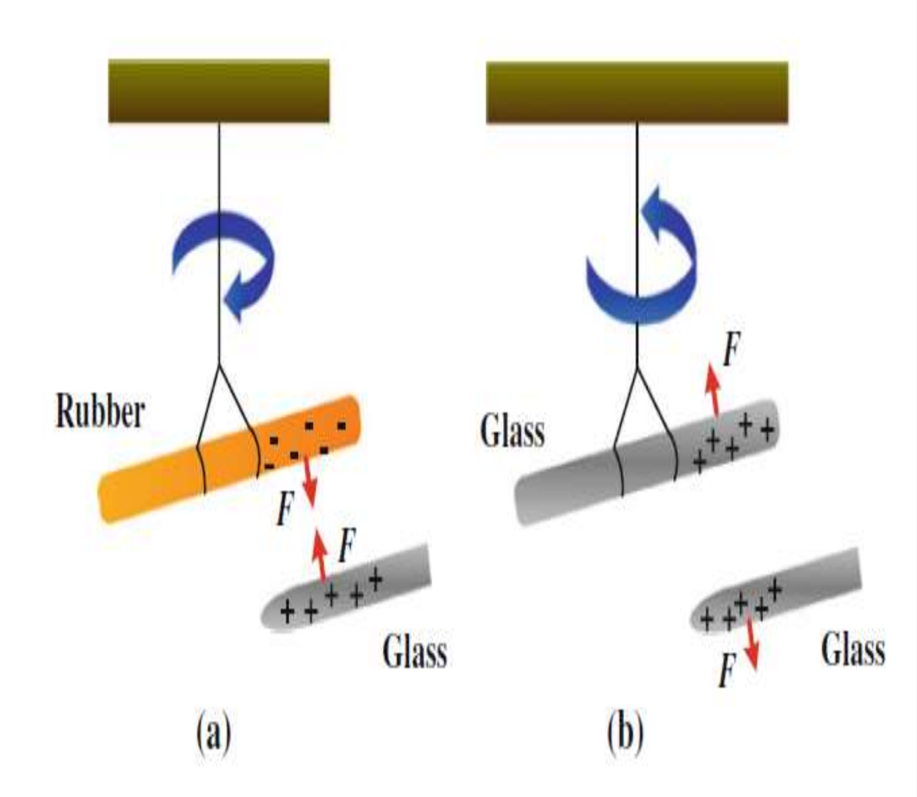


Fig 1

Electrostatics

1- Electric Charge

- Generally, all bodies are electrified by:

  1- Friction.

  2- Contact with another electrified body.

  3- By connecting the body to a terminal of an electric generator.

- Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

- In addition to the existence of two types of charge, several other properties of charge have been discovered:

Electrostatics

1- Electric Charge

- **Charge is quantized**: This means that electric charge comes in discrete amounts, and there is a smallest possible amount of charge that an object can have. In the SI system, this smallest amount is $e \equiv 1.602 \times 10{-}19$ C.

- **The magnitude of the charge is independent of the type**: The smallest possible positive charge is $+1.602 \times 10^{-19}$ C, and the smallest possible negative charge is -1.602×10^{-19} C; these values are exactly equal.

- **Charge is conserved**: Charge can neither be created nor destroyed; it can only be transferred from place to place, from one object to another.

Electrostatics

2- Electrostatic forces (Coulomb's Law)

- *This equation works for only charged particles (and a few other things that can be treated as particles).*

- Coulomb's Law resembles Newton's force law that describes the universal gravitation between two objects of masses m1 and m2 that are separated by a distance r:

$$F = G\frac{m_1 m_2}{r^2}$$ Newton's gravitational law

G: the gravitational constant. $G = 6.67 \times 10^{-11}\ \mathrm{N.m^2/kg^2}$

- Both the inverse square laws describe a property of interacting objects where charges are involved in one case and masses in the other. The laws differ in that the electrostatic forces between two charged particles may be either attractive or repulsive, but gravitational forces are always attractive.

Electrostatics

2- Electrostatic forces (Coulomb's Law)

In an experiment to measure the magnitude of the electrical force F between two charged particles separated by a distance r and having charges q1 and q2, Charles Coulomb was able to find that:

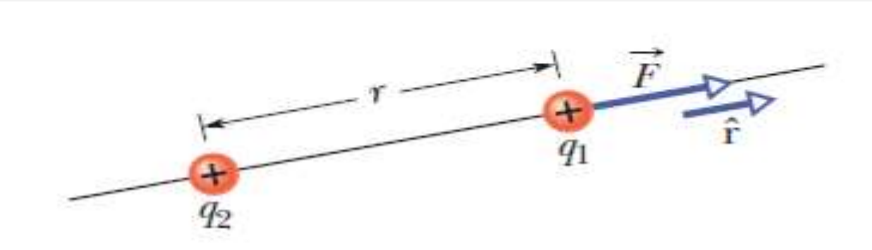


Fig 2:The electrostatic force on particle 1 can be described in terms of a unit vector along an axis through the two particles, radially away from particle 2.

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

This formula is known as **Coulomb's Law**

K: a constant called the Coulomb constant. $K = \frac{1}{4\pi\varepsilon_0} = 8.9876.10^9\, N.m^2/C^2$

ε_0: is known as the permittivity of free space $\varepsilon_0 = 8.8542.10^{-12}\, C^2/N.m^2$

Electrostatics

2- Electrostatic forces (Coulomb's Law)

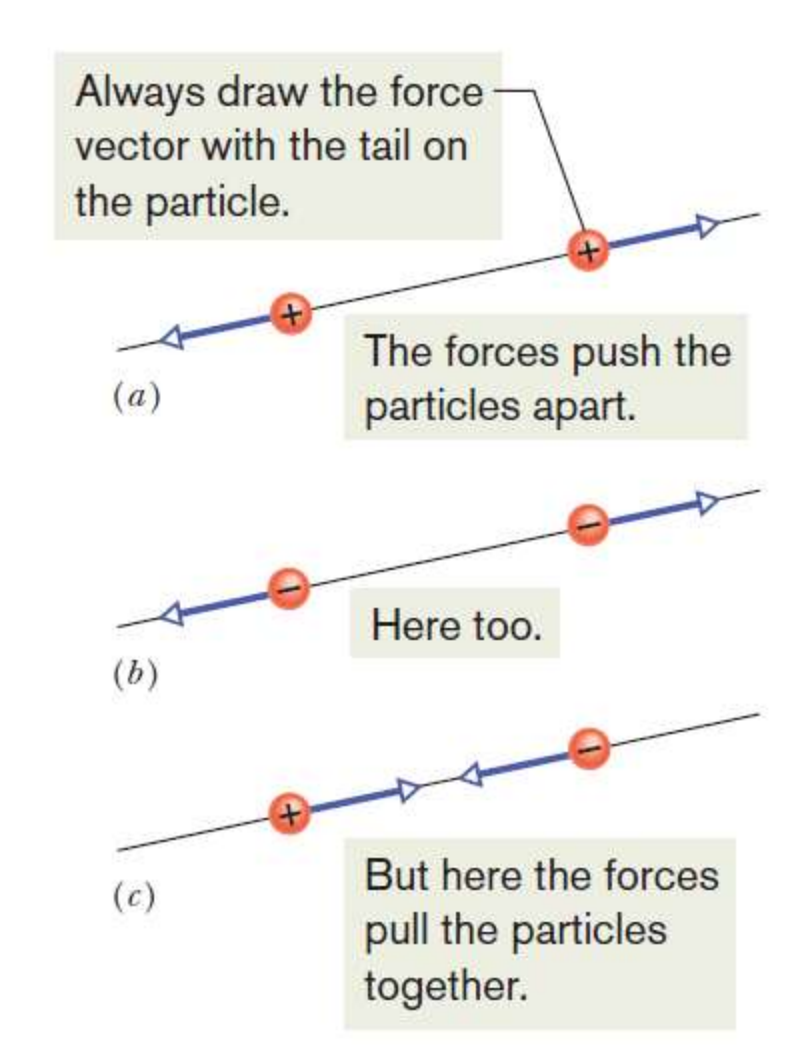


Fig 3:Two charged particles repel each other if they have the same sign of charge, either (a) both positive or (b) both negative.

(c) They attract each other if they have opposite signs of charge.

Electrostatics

2- Electrostatic forces (Coulomb's Law)

Multiple Forces

As with all forces, the electrostatic force obeys the principle of superposition. Suppose we have n charged particles near a chosen particle called particle 1; then the net force on particle 1 is given by the vector sum

$$\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n},$$

If you want to know the net force acting on a chosen charged particle that is surrounded by other charged particles:

- clearly identify that chosen particle and then find the force on it due to each of the other particles.
- Draw those force vectors in a free-body diagram of the chosen particle, with the tails anchored on the particle.

Electrostatics

2- Electrostatic forces (Coulomb's Law)

Multiple Forces

→ add all those forces as vectors according to the rules, not as scalars. (You cannot just add up their magnitudes.) The result is the net force (or resultant force) acting on the particle.

Example:

Consider three point charges located at the corners of a right triangle as shown in Figure 4, where q1 = q3= 5.00 µC , q2 = -2.00 µC , and a = 0.1 m.

- Find the resultant force exerted on q3.

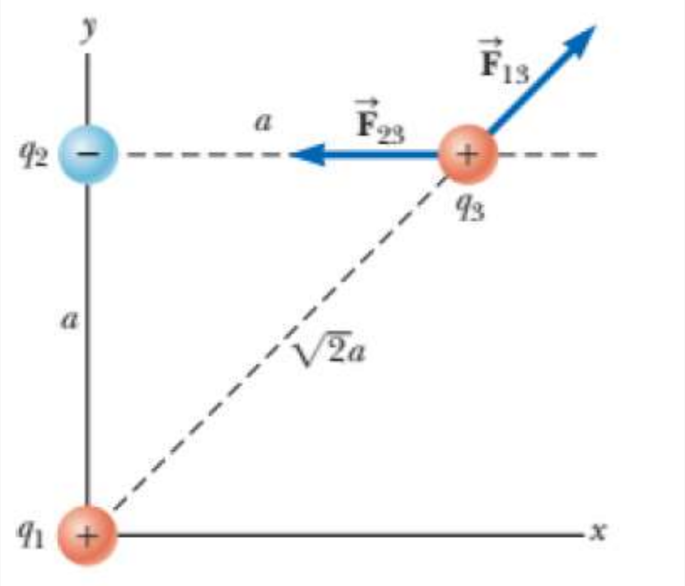


Fig 4

Electrostatics

3- The Electric Field

Electric field is said to exist in the region of space around a charged object, the source charge. The electric field vector at a point in space is defined as the electric force acting on a positive test charge placed at that point divided by the test charge.

Note that $\vec{E}$ is the field produced by some charge or charge distribution separate from the test charge q_0 , an electric field exists at a point if a test charge q_0 at that point experiences an electric force.

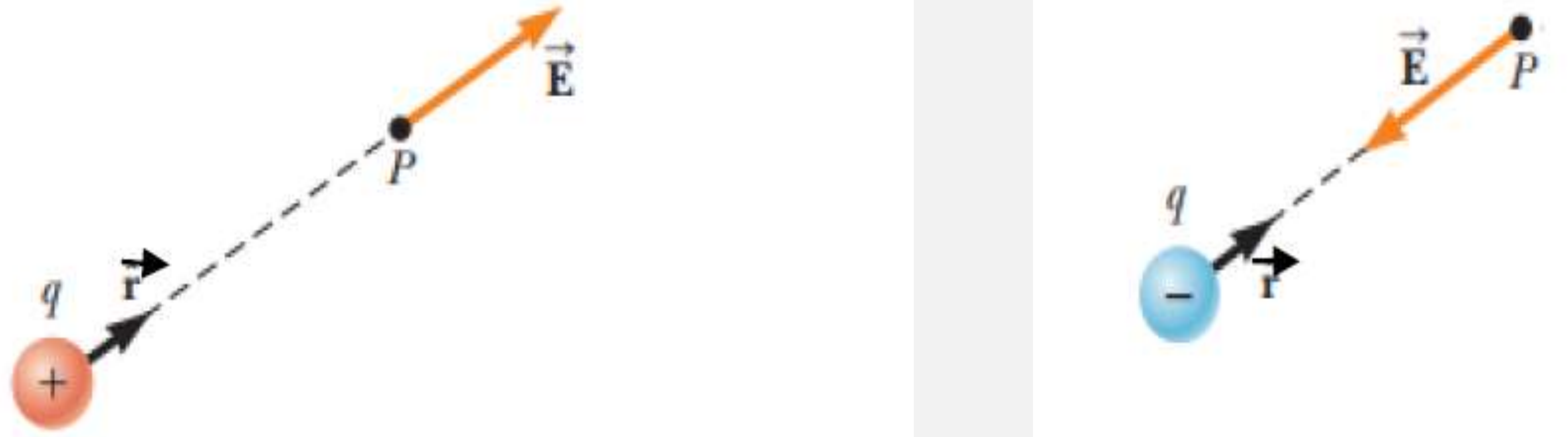
If an arbitrary charge q_0 is placed in an electric field $\vec{E}$, it experiences an electric force given by:

$$\vec{F}_e = q_0 . \vec{E}$$

Electrostatics

3- The Electric Field

The vector $\vec{E}$ has the SI units of newton's per coulomb (N/C). The direction of $\vec{E}$ as shown in Figure 5:



For a positive source charge, the electric field at P points radially outward from q

For a negative source charge, the electric field at P points radially inward toward q.

Fig 5

Electrostatics

3- The Electric Field

Electric Field Lines

The concept of electric field lines was introduced by Faraday as an approach to help us visualize electric fields.

An electric field line is an imaginary line drawn in such a way that the direction of its tangent at any point is the same as the direction of the electric field vector $\vec{E}$ at that point

Since the direction of an electric field generally varies from one point to another, the electric field lines are usually drawn as curves.

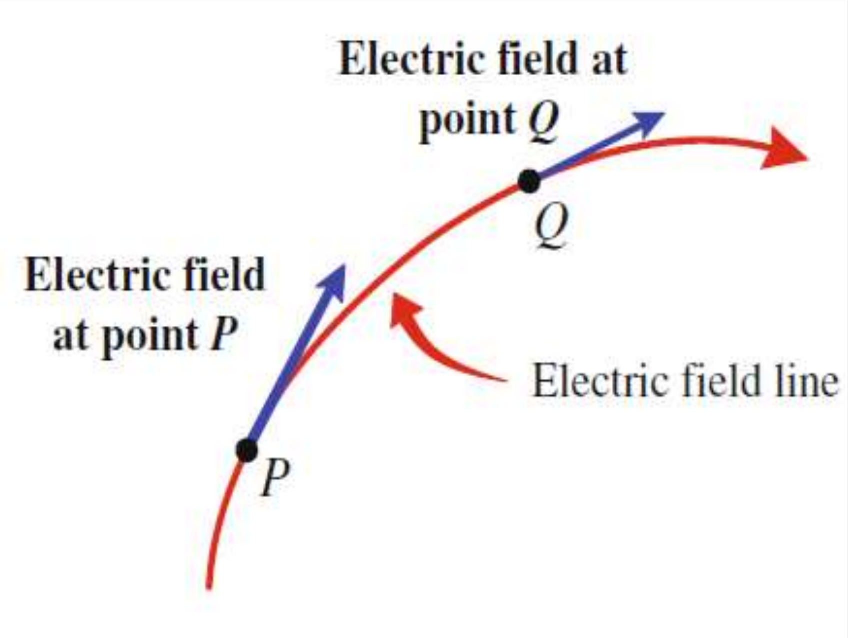


Fig 6:The direction of the electric field

Electrostatics

3- The Electric Field

Electric Field Lines

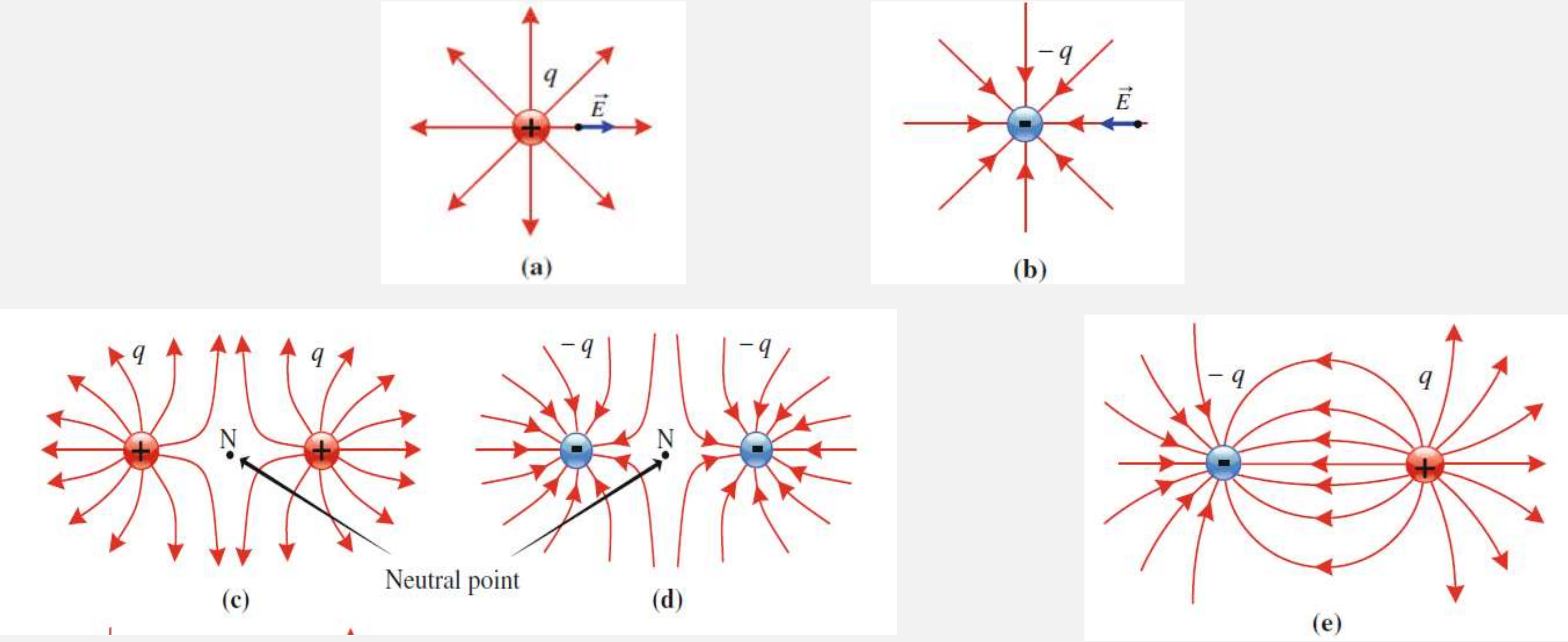


Fig 7:The figure shows the electric field lines

Electrostatics

3- The Electric Field

Electric Field Lines

The field lines are the continuity of the vectors of the electric field created by any charge. We distinguish according to the sign of charge two cases for the lines of the electric field.

- (a) For a positive point charge, the field lines are directed radially outward.
- (b) For a negative point charge, the field lines are directed radially inward.

The number of field lines leaving the positive charge equals the number terminating at the negative charge.

Electrostatics

3- The Electric Field

The Electric Field Due to a Point Charge

To find the electric field due to a charged particle (often called a point charge),we place a positive test charge at any point near the particle, at distance r. From Coulomb's law the force on the test charge due to the particle with charge q is:

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\,\hat{r}$$

we can now write the electric field set up by the particle (at the location of the test charge) as:

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{r}$$

we can now write the electric field set up by the particle (at the location of the test charge) as:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$$

Electrostatics

3- The Electric Field

The Electric Field Due to a Point Charge

In general, if several electric fields are set up at a given point by several charged particles, we can find the net field by placing a positive test particle at the point and then writing out the force acting on it due to each particle. Forces obey the principle of superposition, so we just add the forces as vectors:

$$\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \cdots + \vec{F}_{0n}.$$

To change over to electric field:

$$\begin{aligned}\vec{E} = \frac{\vec{F}_0}{q_0} &= \frac{\vec{F}_{01}}{q_0} + \frac{\vec{F}_{02}}{q_0} + \cdots + \frac{\vec{F}_{0n}}{q_0} \\ &= \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n.\end{aligned}$$

The electric fields also obey the principle of superposition.

Electrostatics

3- The Electric Field

Electric Field of a Continuous Charge Distribution

The electric field at point P due to a continuous charge distribution shown in Fig.8 can be evaluated by:

→ Dividing the charge distribution into small elements, each of charge Δq_n that is located relative to point P by the position vector $\vec{r}_n = r_n \hat{\vec{r}}_n$.

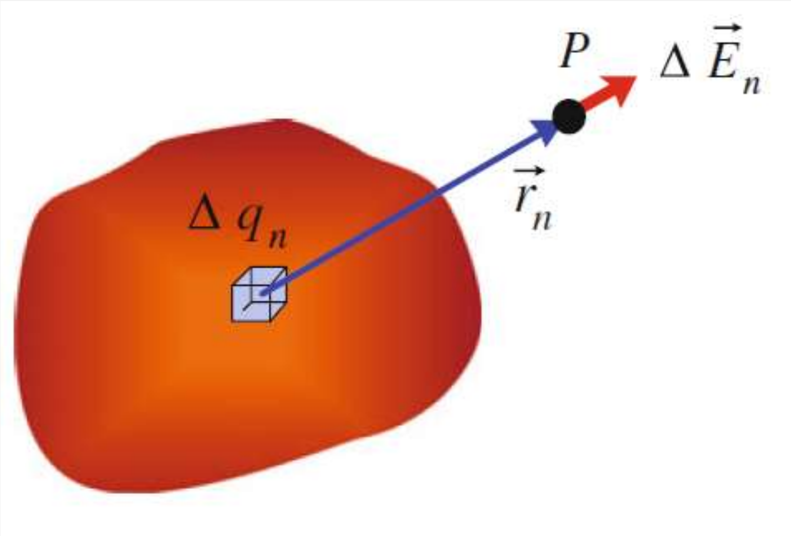


Fig 8: The electric field $\vec{E}$ at point P due to a continuous charge Distribution

Electrostatics

3- The Electric Field

Electric Field of a Continuous Charge Distribution

- Using the electric field equation to evaluate the electric field $\Delta\overrightarrow{E_n}$ due to the n^{th} element as follows:

$$\Delta \vec{E}_n = k\frac{\Delta q_n}{r_n^2}\hat{r}_n$$

- Using the electric field equation to evaluate the electric field $\Delta\overrightarrow{E_n}$ due to the n^{th} element as follows:

$$\vec{E} \approx k\sum_n \frac{\Delta q_n}{r_n^2}\hat{r}_n$$

- Evaluating the total electric field at P due to the continuous charge distribution in the limit $\Delta q_n \to 0$ as follows:

$$\vec{E} = k\lim_{\Delta q_n \to 0}\sum_n \frac{\Delta q_n}{r_n^2}\hat{r}_n = k\int \frac{dq}{r^2}\hat{r}$$

where the integration is done over the entire charge distribution

Electrostatics

3- The Electric Field

Electric Field of a Continuous Charge Distribution

Now we consider cases were the total charge is uniformly distributed on a line, on a surface, or throughout a volume. It is convenient to introduce the charge density as follows:

- When the charge Q is uniformly distributed along a line of length L, the linear charge density λ is defined as:

$$\lambda = \frac{Q}{L}$$

λ has the units of coulomb per meter (C/m)

- When the charge Q is uniformly distributed on a surface of area A, the surface charge density σ is defined as:

$$\sigma = \frac{Q}{A}$$

σ has the units of coulomb per square meter (C/m2)

Electrostatics

3- The Electric Field

Electric Field of a Continuous Charge Distribution

- When the charge Q is uniformly distributed throughout a volume V, the volume charge density ρ is defined as:

$$\rho = \frac{Q}{V}$$

ρ has the units of coulomb per cubic meter (C/m3)

Accordingly, the charge dq of a small length dL, a small surface of area dA, or a small volume dV is respectively given by:

$$dq = \lambda\, dL, \quad dq = \sigma\, dA, \quad dq = \rho\, dV$$

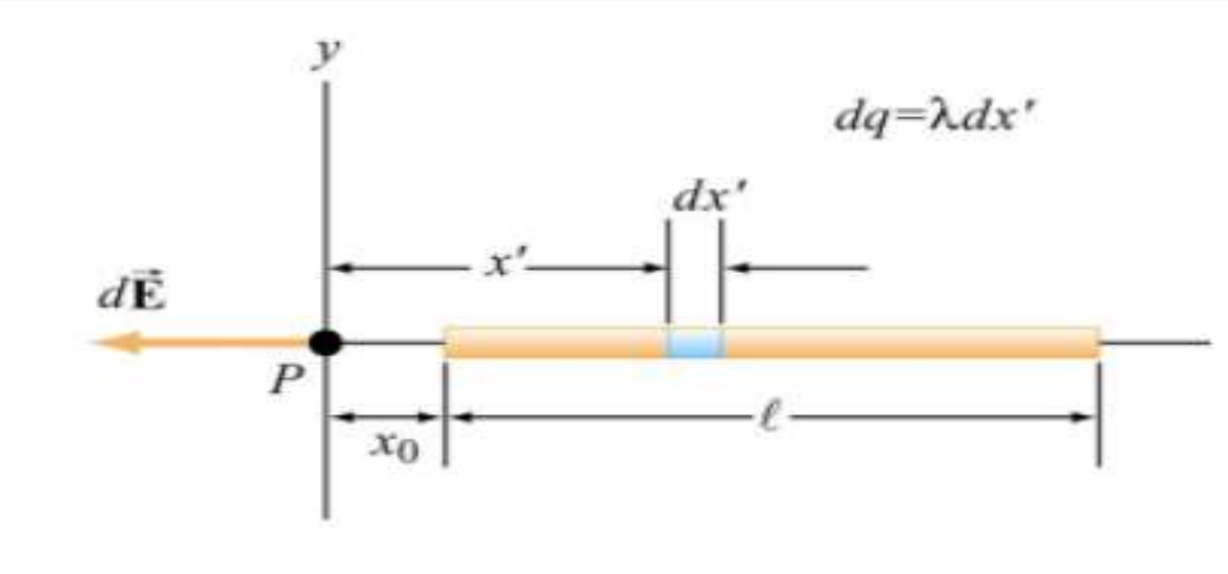
Electrostatics

3- The Electric Field

Electric Field of a Continuous Charge Distribution

Example 1:

A rod of length l, with a uniform positive charge density λ and a total charge Q is lying along the x - axis. Calculate the electric field at a point P located along the axis of the rod and a distance x_0 from one end.



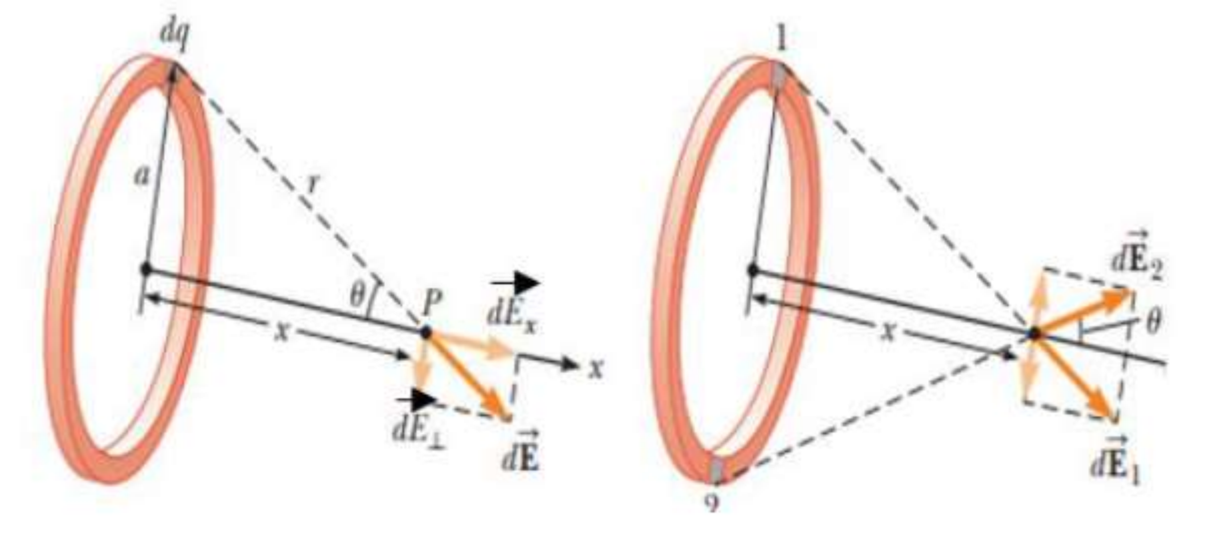
Electrostatics

3- The Electric Field

Electric Field of a Continuous Charge Distribution

Example 2:

A ring of radius a carries a uniformly distributed positive total charge Q. Calculate the electric field due to the ring at a point P lying a distance x from the center of the ring along its axis of symmetry.



Electrostatics

4- Electric Potential:

Electric potential at a point in an electric field is equal to the amount of work done in bringing a unit positive charge from infinity to that point. The work done in transferring the charge placed in an electric field E created by some source charge distribution equals the product of the force on the test charge and the parallel component of displacement.

- The internal work done within the charge field system by the electric field on the charge for an infinitesimal displacement $\overrightarrow{ds}$ of a point charge q immersed in an electric field is:

$$W = \overrightarrow{F_e}.\overrightarrow{ds} = q\overrightarrow{E}.\overrightarrow{ds}$$

- In a system, the internal work is equal to the negative of the change in the potential energy.

$$dU = -W = -q\overrightarrow{E}.\overrightarrow{ds}$$

Electrostatics

4- Electric Potential:

- The change in electric potential energy of the system, for a finite displacement of the charge from some point A in space to some other point B is:

$$\Delta U = -q\int_{A}^{B} \vec{E}.\vec{ds}$$

- Dividing potential energy by charge gives a physical quantity that depends solely on the charge distribution of the source and has a value at every point in an electric field. This quantity is called the electric potential V:

$$V = \frac{U}{q}$$

- At any distance r from the charge, the electric potential for a point charge is:

$$V = K\frac{q}{r}$$

Electrostatics

4- Electric Potential:

- For a group of point charges, we have applying the superposition principle to obtain the electric potential resulting and we can write the total electric potential at P as:

$$V = K\sum_i \frac{q_i}{r_i}$$

- The electric potential V and the electric field $\vec{E}$ are related , which tells us how to find ΔV if the electric field $\vec{E}$ is known. We calculate the value of the electric field if the electric potential is known in a certain region, the potential difference dV between two points a distance ds apart can be expressed as:

$$dV = -\vec{E}.\vec{ds}$$

$$\vec{E} = -\overrightarrow{grad V} = -\vec{\nabla}V = -\left(\frac{\partial V}{\partial x}\vec{i} + \frac{\partial V}{\partial y}\vec{j} + \frac{\partial V}{\partial z}\vec{k}\right)$$

Electrostatics

4- Electric Potential:

- The potential is constant along an equipotential surface:

$$\begin{cases} dV = 0 \\ -\vec{E}.\vec{ds} = 0 \Rightarrow \vec{E} \perp \vec{ds} \end{cases}$$

- $\vec{E}$ must be perpendicular to the displacement along the equipotential surface. This result shows that the equipotential surfaces must always be perpendicular to the electric field lines passing through them.

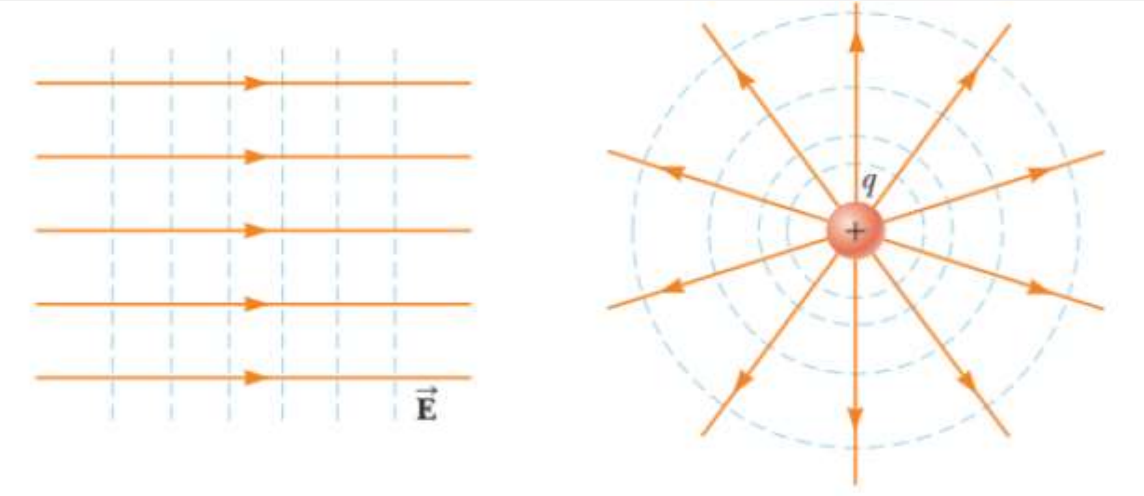


Fig 9: some representative equipotential surfaces

Electrostatics

4- Electric Potential:

Electric potential energy:

- The electric potential energy of a pair of point charges q_1 and q_2 can be found as follows:

$$U = K\frac{q_1 q_2}{r_{12}}$$

- For a collection of n point charges, we find:

$$U = \frac{1}{2}\sum_{i=1}^{n} q_i V(r_i)$$

- The work needed to bring one-point charge q from infinity to a point P in the field of another point charge equals:

$$W = \Delta U = -q\int_{\infty}^{P} \vec{E}.\vec{ds} = -q\int_{\infty}^{P} -dV = qV_P$$

Electrostatics

5- Electric dipole:

Electric dipoles are a specific combination of a positive charge +Q held at a fixed distance l , from an equal and opposite charge -Q, as illustrated:

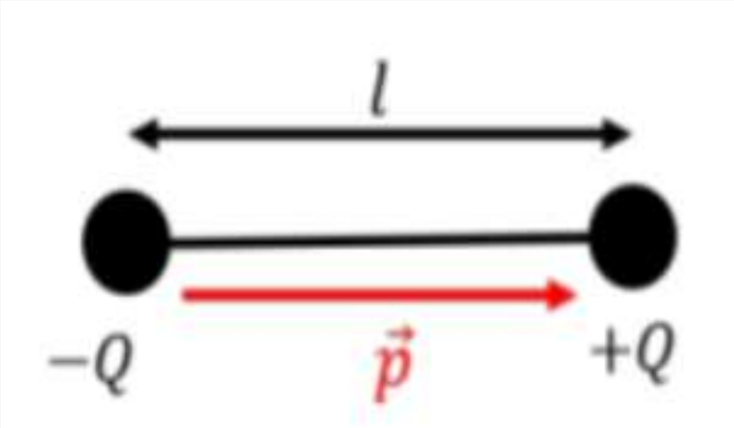


Fig 10: An electric dipole and its corresponding dipole vector $\vec{p}$

Dipoles can be represented by their "electric dipole vector" (or "electric dipole moment"), $\vec{p}$, defined to point in the direction **from the negative charge to the positive charge**, with magnitude:

$$p = Ql$$

Electrostatics

5- Electric dipole:

Dipoles arise often in nature, for example, a water molecule can be modeled as a dipole, because the two hydrogen atoms are not symmetrically arranged around the oxygen atom. The electrons in a water molecule tend to stay closer to the oxygen atom, which acquires an excess of 2 electrons, while each proton has a deficit of 1 electron, resulting in a separation of charge (polarization), which can be modeled as a an electric dipole, as in Figure

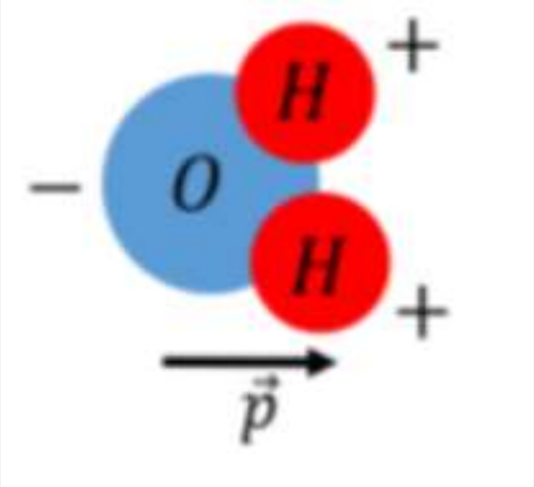


Fig 11: A water molecule can be modeled as an electric dipole.

Electrostatics

5- Electric dipole:

When a dipole is immersed in a uniform electric field, as illustrated in Figure 12, the net force on the dipole is zero because the force on the positive charge will always be equal and in the opposite direction from the force on the negative charge.

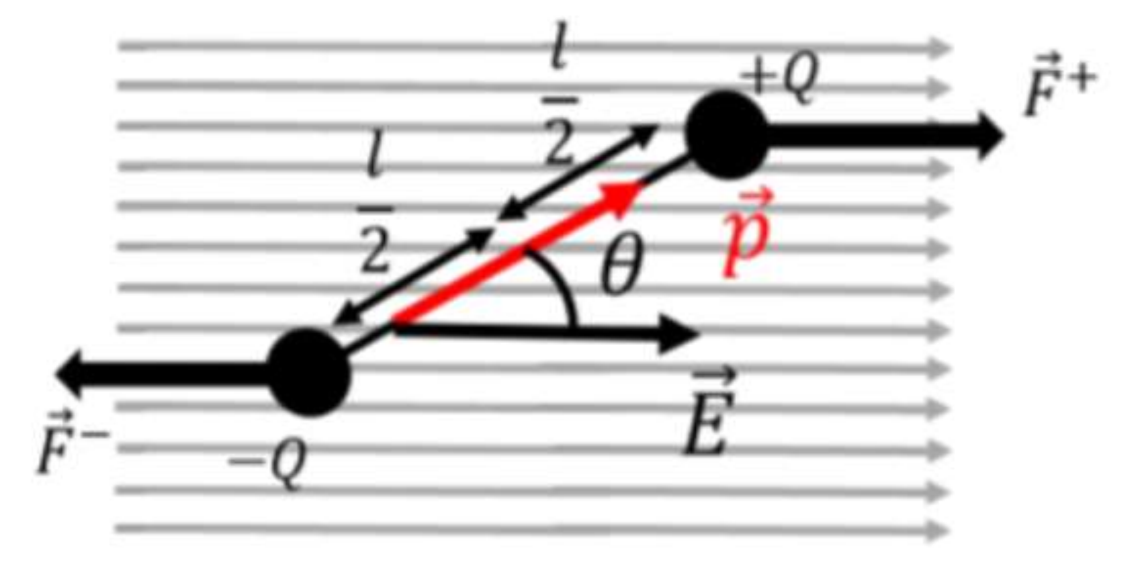


Fig 12: An electric dipole in a uniform electric field.

5- Electric dipole:

Although the net force on the dipole is zero, there is still a net torque about its center that will cause the dipole to rotate (unless the dipole vector is already parallel to the electric field vector). If the dipole vector makes an angle θ, with the electric field vector (as in Figure 12), the magnitude of the net torque on the dipole about an axis perpendicular to the page and through the center of the dipole is given by:

$$\tau = \frac{l}{2} F^{+} \sin\theta + \frac{l}{2} F^{-} \sin\theta = \frac{l}{2} QE \sin\theta + \frac{l}{2} QE \sin\theta = QlE \sin\theta = pE \sin\theta$$

In Figure 12, the torque vector is into the page (the forces will make it rotate clockwise), which is the same direction as the cross product, $\vec{p} \times \vec{E}$.

5- Electric dipole:

Note that the magnitude of the torque is also equal to the magnitude of the cross product. Thus, in general, the torque vector on a dipole $\vec{p}$, from an electric field $\vec{E}$, is given by:

$$\vec{\tau} = \vec{p} \times \vec{E}$$

In particular, note that the torque is zero when the dipole and electric field vectors are parallel. Thus, a dipole will always experience a torque that tends to align it with the electric field vector. The dipole is thus in a stable equilibrium when it is parallel to the electric field.

Electrostatics

6- Gauss's Law:

Although Coulomb's law is the governing law in electrostatics, its form does not always simplify calculations in situations involving symmetry. In this part, we introduce Gauss's law as an alternative method for calculating electric fields of certain highly symmetrical charge distribution systems.

Electric Flux

Consider a uniform electric field $\vec{E}$ penetrating a small area A oriented perpendicularly to the field as shown in Fig. 13.

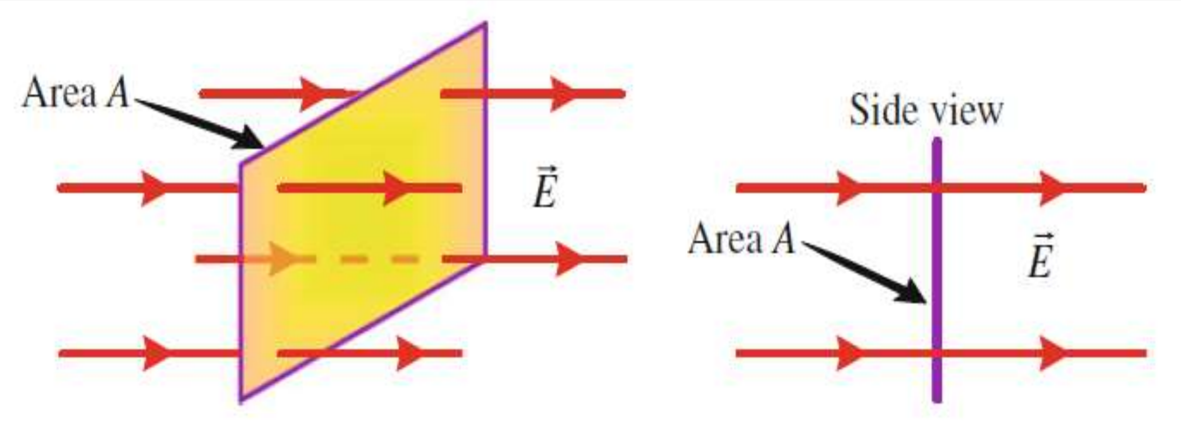


Fig 13: Electric field lines representing a uniform electric field $\vec{E}$ that penetrates an area A perpendicularly.

Electrostatics

6- Gauss's Law:

Electric Flux

Recall that the number of electric field lines per unit area (measured in a plane perpendicular to the lines) is proportional to the magnitude of $\vec{E}$. Therefore, the total number of lines penetrating the surface is proportional to EA. This product is called the electric flux $\boldsymbol{\Phi}_E$. Thus:

$$\Phi_E = EA$$

- The SI units for $\boldsymbol{\Phi}_E$ is newton-meters square per coulomb (N.m2/C).
- Electric flux is proportional to the number of electric field lines penetrating a certain area.

Electrostatics

6- Gauss's Law:

Electric Flux

Generally, the electric field may vary over the surface of any shape. Let us consider the general surface depicted by the shape in Fig. 14 and calculate the electric flux over the whole surface.

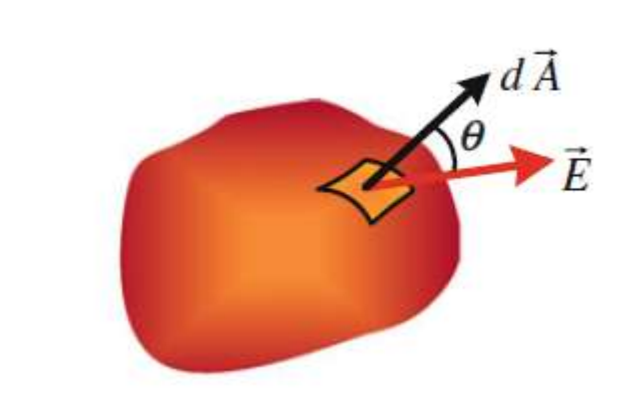


Fig 14: The differential surface vector area $\overrightarrow{dA}$ of magnitude dA and direction perpendicular to the differential surface area and pointing outwards.

6- Gauss's Law:

Electric Flux

We start by considering a differential vector surface area $\overrightarrow{dA}$ to be normal to the surface and to point outwards at a specific location. If the electric field vector at this location is $\vec{E}$, then the differential electric flux d$\boldsymbol{\Phi}_E$ through this differential area will be:

$$d\Phi_E = \vec{E} \bullet d\vec{A}$$

We integrate this relation over a surface S to get the electric flux as:

$$\Phi_E = \int_S \vec{E} \bullet d\vec{A}$$

Generally, $\boldsymbol{\Phi}_E$ depends on the field pattern and the surface shape.

Electrostatics

6- Gauss's Law:

Electric Flux

According to the definition of the vector area $\overrightarrow{dA}$ which always points outwards, the sign of the flux depends on the angle between $\vec{E}$ and $\overrightarrow{dA}$ as follows:

- If θ <90°, then $\vec{E}$ crosses the surface from the inside to the outside and hence $d\boldsymbol{\Phi}_E = \vec{E} \bullet \overrightarrow{dA}$ is positive.
- If θ = 90°, then $\vec{E}$ grazes the surface and hence $d\boldsymbol{\Phi}_E = \vec{E} \bullet \overrightarrow{dA}$ is zero.
- If 90°<θ <180° , then $\vec{E}$ crosses the surface from the outside to the inside and hence $d\boldsymbol{\Phi}_E = \vec{E} \bullet \overrightarrow{dA}$ is negative.

The net flux through a surface is proportional to the net number of electric field lines leaving the surface. If more lines are entering than leaving, then the net flux is negative. If more lines are leaving than entering, then the net flux is positive.

Electrostatics

6- Gauss's Law:

Electric Flux

We can write the net flux through a closed surface as:

$$\Phi_E = \oint \vec{E} \cdot d\vec{A}$$

where the symbol $\oint$ represents an integral over a closed surface.

Gauss's Law

In this section, we introduce a new foundation of Coulomb's law, called **Gauss's law**. This law can be used to take advantage of symmetry in the problem under consideration. Central to Gauss's law is a hypothetical closed surface called a **Gaussian surface**.

Now consider several closed Gaussian surfaces surrounding the charge as shown in Fig.15.

Electrostatics

6- Gauss’s Law:

Gauss’s Law

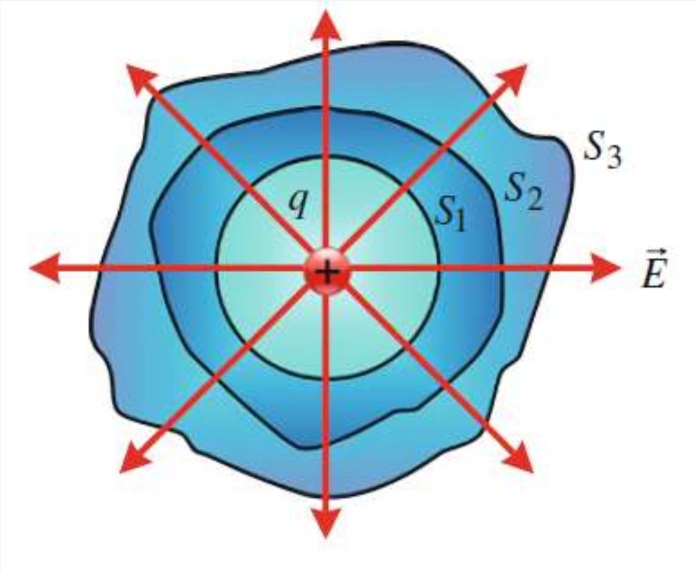


Fig 15: Different closed Gaussian surfaces enclosing a point charge q.

number of electric field lines passing through the spherical surface S1 is the same as the number of lines passing through the non-spherical surfaces S2 and S3. Therefore, we conclude that the flux through any closed Gaussian surface surrounding the point charge q is $q/\boldsymbol{\varepsilon}_0$.

Electrostatics

6- Gauss's Law:

Gauss's Law

Gauss's Law → The net electric flux through any closed surface is equal to the net charge inside the surface divided by the permittivity of free space $\boldsymbol{\varepsilon}_0$.

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{in}}}{\epsilon_\circ}$$

q_{in}: the net charge inside the Gaussian surface.

$\vec{E}$: the total electric field at any point on the surface, which includes contributions from charges inside and/or outside.

Gauss's law is very useful in calculating electric fields in situations where the charge distributions have planar, cylindrical, or spherical symmetry. In these charge distribution systems, one must carefully construct the imaginary Gaussian surface such that it simplifies the integral.

Electrostatics

6- Gauss's Law:

Gauss's Law

This can be done by trying to satisfy one or more of the following conditions:

1: The value of the field over the surface is constant, E = constant.

2: The dot product $\vec{E} \bullet \overrightarrow{dA}$ is E dA because $\vec{E} \,//\, \overrightarrow{dA}$.

3: The dot product $\vec{E} \bullet \overrightarrow{dA}$ is zero because $\vec{E} \perp \overrightarrow{dA}$.

4: The value of the field over the surface is zero, E = 0.