Electrostatic Force

Properties of Electric Charges

The text of the law of conservation of charge: -
Charge cannot be Created or Destroyed .

Electric charge is always conserved in an isolated system. That is, when we rub two objects together, the charge formed does not arise out of nowhere. Rather, it results from a state of electrification (the charging process) as a result of the transfer of charge from one body to another.

One object acquires a specific negative charge, while the second object acquires a positive charge of the same amount. For example, when a rod of glass is rubbed with a piece of silk as shown in Figure (1), the silk gets a negative charge equal in amount to the positive charge that formed on the glass rod.

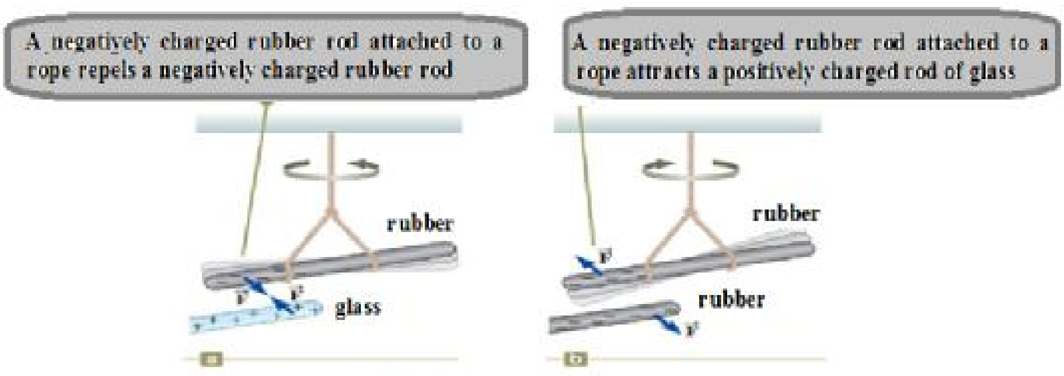


Figure 1: Electrical forces between
(a) Two charged particles with different charges
(b) Two charged particles with similar charges

From the atomic structure, we conclude that electrons are transferred during the rubbing process

from glass to silk. Similarly, when a rubber rod is rubbed into a piece of fur, electrons move from the fur to the rubber, which shows a negative charge on the rubber and a positive charge on the fur. This process occurs because uncharged neutral materials contain a number of positive charges (protons inside the atom nucleus). equal to the number of negative charges (electrons in orbitals surrounding the nucleus).

Type of Charge

1. **positive electric charge + protons (*p +*)**
2. **Negative electric charge - electrons (*e –*)**

Electrons have a negative charge (*e-*) and the proton has a positive charge (*e +*) equal to the charge of the electron, but with an opposite sign.

The smallest unit of free charge in nature is the electron charge, e. It is ($-e$) for an electron and ($+e$) for a proton. It has the following value:

($e = 1.60218 \times 10^{-19}\ C$).

The charge and mass of each of the electron, proton and neutron are shown in Table (1). Note that the electron and proton are the same in the amount of their charge, but they differ in their mass. On the other hand, both the proton and the neutron have the same mass, but differ in charge.

Table (1): Charge and mass of the electron, proton and neutron

Particle	Mass (kg)	Charge (C)
Electron (e)	9.1094×10^{-31}	$-1.6021765 \times 10^{-19}$
Proton (p)	1.67262×10^{-27}	$+1.6021765 \times 10^{-19}$
Neutron (n)	1.67262×10^{-27}	0

Very important notes

1- The proton is inside the nucleus of the atom and its charge is positive and its magnitude is equal to the magnitude of the charge of the electron.

Matter is made up of atoms, and each atom contains:

(a) - the nucleus and contains positive (p +) protons and neutral neutrons

(b) - Electrons (e-) rotate at a very high speed around the nucleus and have a negative (-) charge.

Note: ***Atoms are electrically neutral when the number of electrons equals the number of protons (the negative charge equals the positive charge)***

2- The charge of an electron or proton is the smallest unit of charge, to measure charges.

3- The charge of any charged body is an integer multiple of the charge of the electron. To calculate the number of electrons for a charged body.

Electric charge (*q*) is quantized, where *q* is the symbol used for charge. This means that the electric charge exists as discrete packets, and we can write that ($q = \pm Ne$), where *N* is an integer.

(nu

4- The amount of charge of an electron

(C is 1.60218×10^{-19}), where (*C*) means a coulomb,and 1coulomb = 6.25×10^{18} *electrons*.

5- Electron mass = $9.1091 \times^{-31}$ Kg.

6- parts of a coulomb:

millicoulomb ($1\ mC=10^{-3}\ C$),

microcoulomb ($1\mu C=10^{-6}\ C$),

nanocoulomb ($1\ nC=10^{-9}C$),

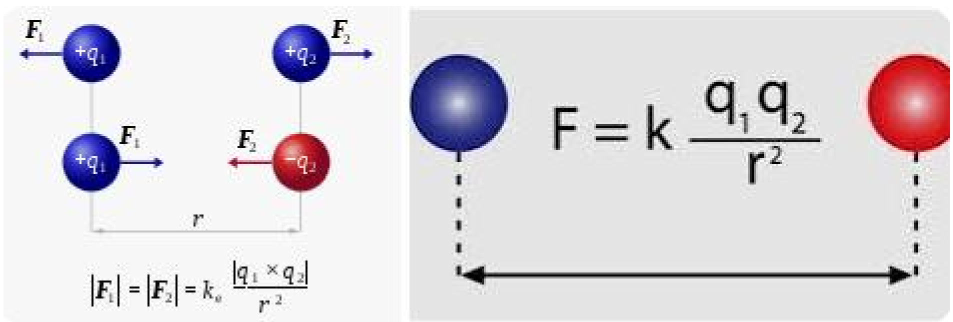
picocoulomb ($1pC=10^{-12}C$).

Materials **can be classified according to the ability of their electrons to move within the material:**
Electrical conductors**: are materials that contain free electrons that are not bound to atoms and can move freely within the material.**
Materials such as: copper, aluminum and silver are good conductors of electricity.

Electric Insulator: They are materials in which all electrons are bound with atoms and cannot move freely within the material.
Materials such as: glass, rubber and dry wood.
Semiconductor :is the third class of materials whose electrical properties fall between insulating and conductive materials, such as: silicon and germanium.

Coulomb's Law

The electrical interaction between point charges (a charged particle of zero size) can be studied through an electric force known as the "Electrostatic Force" arising between two stable charged particles through Coulomb's law, which states "*the force of attraction or repulsion between two charges in vacuum is directly proportional to the value absolute net of the product of their charges, and inversely with the square of the distance between them*".



Where (*k_e*) is a constant known as "*Coulomb's Constant*". Electric forces are conserved forces, just like gravitational forces.

The value of Coulomb's constant depends on the choice of units. The unit of electric charge is the coulomb and it is denoted by the symbol (*C*) and the coulomb constant (k_e) in standard units (SI) has the value:

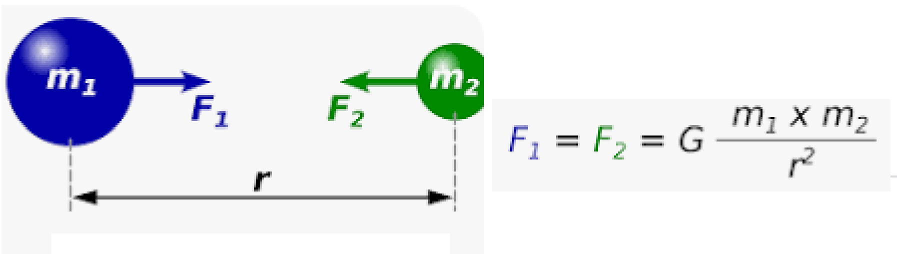
$$k_e = 8.9876 \times 10^9 \ N.m^2/C^2$$

The constant (k_e) can also be written as:

Whereas the constant ϵ_o (pronounced epsilon) is known as the "Permittivity Constant" of a vacuumhas the value:

Newton's law of universal gravitation

It states that: any two objects in the universe have an gravitational force between them that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.



Where *G* is the universal gravitational constant

$$G = 6.67 \times 10^{-11} (N.m^2)/Kg^2$$

Directional form of Coulomb's law

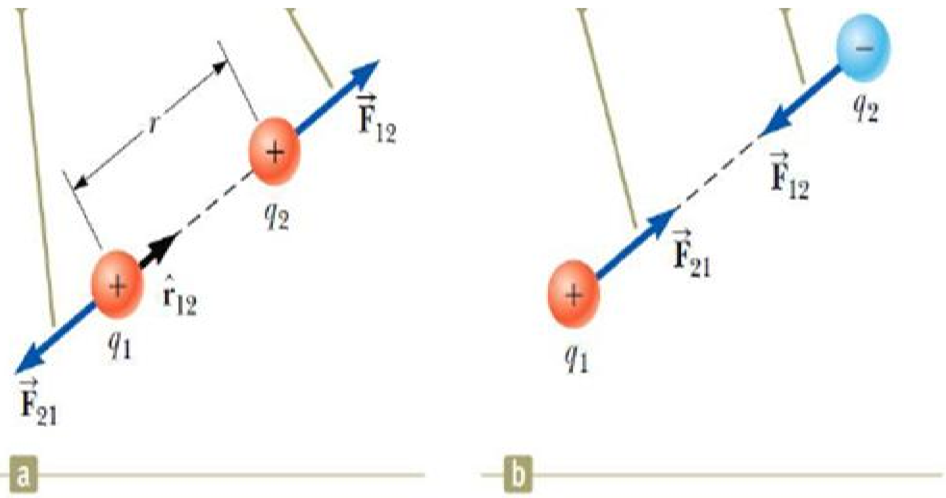
When we deal with Coulomb's law, remember that force is a vector quantity and we must deal with it on this basis. Coulomb's law is expressed in its vector form through the electric force exerted by charge q_1 on charge q_2 we express it as follows:

$$\overrightarrow{F_e} = k_e \frac{|q_1||q_2|}{r^2}\,\hat{r}$$

Where $\hat{r}$ is the unit vector and is directed from charge q_1 to charge q_2 as shown in Figure (2) Since the electric force is subject to Newton's third law, the electric force exerted by charge q_2 on charge q_1 is equal in magnitude to the electric force exerted by charge q_1 on charge q_2 In the opposite direction, that is:

$$\overrightarrow{F_{12}} = \overrightarrow{F_{21}}$$

If the charge q_1 and the charge q_2 have an opposite sign as in the figure below, then the product of the two charges q_1q_2 is negative and the electric force on one of the two particles is directed towards the other particle. These signals describe the relative direction of the force but not the absolute direction. The negative sign indicates that the force is attractive and the positive sign indicates that the force is repulsive.



Note: When there are more than two charges, the net electric force acting on one of these charges is equal to the vector sum of the forces exerted by the other charges. For example, if there are four charges, the net force exerted by particles 2, 3, and 4 on particle 1 is:

$$\overrightarrow{F_1} = \overrightarrow{F_{21}} + \overrightarrow{F_{31}} + \overrightarrow{F_{41}}$$

Example 1: In the hydrogen atom, the hydrogen atom, the distance separating the electron from the proton in The Hydrogen Atom is estimated at 5.3 x 10^{-11} m. Find the magnitude of the electric force and the gravitational force between them.

$$F_e = k_e \frac{|q_1||q_2|}{r^2} = (8.99 \times 10^9 N.\frac{m^2}{C^2}) \frac{(1.6 \times 10^{-19} C)^2}{(5.3 \times 10^{-11} m)^2}$$

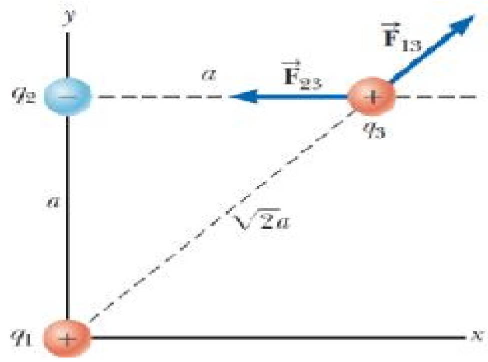
$$= 8.2 \times 10^{-8}\ \mathrm{N}$$

$$F_g = G \frac{m_e m_p}{r^2}$$

$$= (6.67 \times 10^{-11} N.\frac{m^2}{kg^2}) \frac{(9.11 \times 10^{-31} kg)(1.67 \times 10^{-27} kg)}{(5.3 \times 10^{-11} m)^2}$$

$$= 3.6 \times 10^{-47}\ \mathrm{N}$$

Example 2: Find the resultant force. Consider that there are three charges placed on the corners of a right-angled triangle as shown in the figure, where the charge $q_1 = q_3 = 5.00\ \mu C$, the charge $q_2 = -2.00\ \mu C$, and the distance ($a = 0.100$ m). Find the net force on q_3.



$$F_{23} = k_e \frac{|q_1||q_3|}{r^2}$$

$$= (8.99 \times 10^9 N.\frac{m^2}{C^2}) \frac{(2.00 \times 10^{-6} C)(5.00 \times 10^{-6} C)}{(0.100 m)^2} = 8.99 N$$

$$F_{13} = k_e \frac{|q_1||q_3|}{(\sqrt{2}a)^2}$$

$$= (8.99 \times 10^9 N.\frac{m^2}{C^2}) \frac{(5.00 \times 10^{-6} C)(5.00 \times 10^{-6} C)}{2(0.100 m)^2} = 11.2 N$$

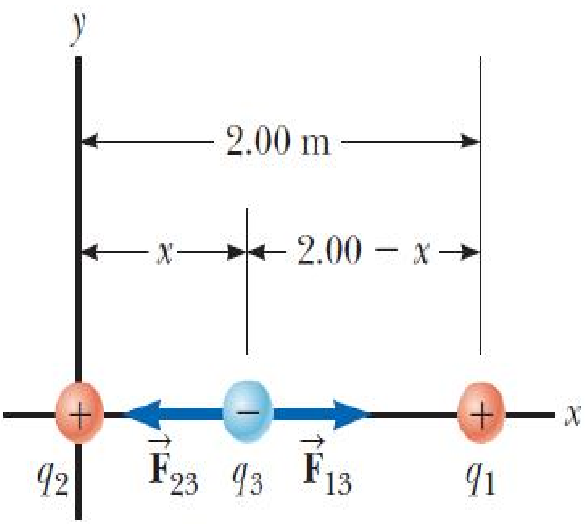
$$F_{13x} = F_{13} cos 45.0^o = 7.94 N$$

$$F_{13y} = F_{13} sin 45.0^o = 7.94 N$$

$$F_{3x} = F_{13x} + F_{23x} = 7.94 N + (-8.99 N) = -1.04 N$$

$$F_{3y} = F_{13y} + F_{23y} = 7.94 N + 0 = 7.94 N$$

Example 3: Where is the net force equal to zero? For three point charges located along the x axis as shown in the figure, the positive charge q_1 = *15.0μC* is located at x = *2.00 m* and the positive charge q_2 = *6.00μC* at the point of origin and the total force acting on the charge q_3 is *zero.* What is the coordinate of charge q_3 with respect to the x axis?



$$\vec{F}_3 = \vec{F}_{23} + \vec{F}_{13} = -k_e \frac{|q_2||q_3|}{x^2}\hat{\imath} + k_e \frac{|q_1||q_3|}{(2.00-x)^2}\hat{\imath} = 0$$

$$k_e \frac{|q_2||q_3|}{x^2} + k_e \frac{|q_1||q_3|}{(2.00-x)^2}$$

$$(2.00 - x)^2 q_2 = x^2 q_1$$

$$(4.00 - 4.00x + x^2)(6.00 \times 10^{-6} C) = x^2(15.0 \times 10^{-6} C)$$

$$3.00x^2 + 8.00x - 8.00 = 0$$

$$x = 0.775m$$

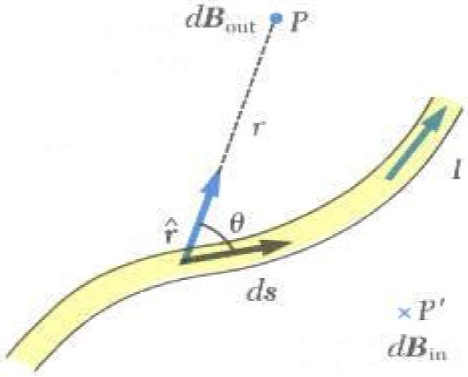
Biot Savart Law

To find the relationship between the current in a wire and the resulting magnetic field at any point in space. They have come up with the following practical facts:

1. The magnetic field vector dB of a small element of wire of length ds at a point P in space is always perpendicular to both the element ds and the displacement vector r that goes from the element of wire ds to point P.

2. The magnitude of the magnetic field, dB, is inversely proportional to the square of the distance, r^2.
3. The magnitude of the dB magnetic field is directly proportional to the current in the wire.

4. The magnitude of the dB magnetic field is directly proportional to sin θ, where the angle θ is the angle between the displacement vector r and the element ds of the wire. These practical results can be summarized in the *Biot-Savart* law.



$$dB = \mu \frac{I.ds.\sin\theta}{r^2}$$

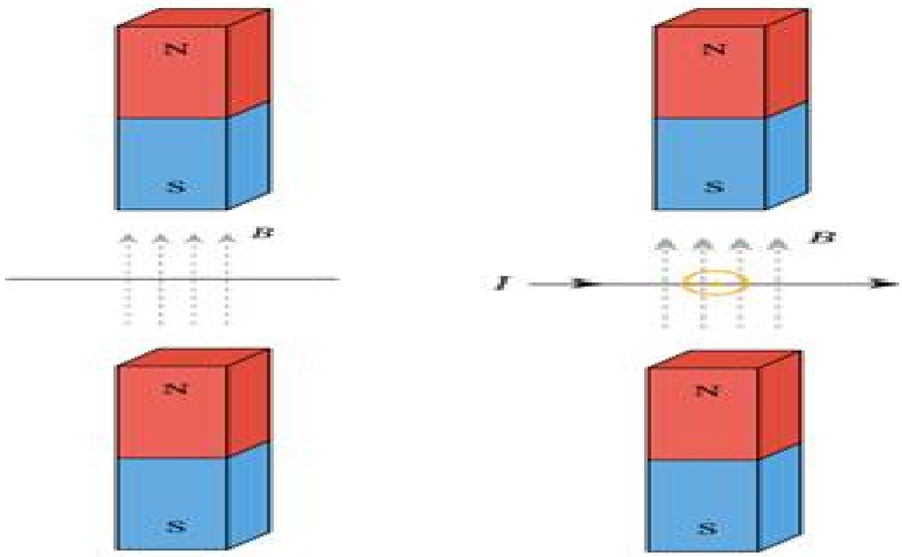
Where μ is a constant whose value depends on the type of units used and the direction of the field is perpendicular to the plane that collects ds , r.

Difference between Biot–Savart Law and Ampère's Law

Both *Ampère's law* and *Biot-Savart law* help us calculate the size of magnetic field lines, but the main difference between *Biot-savart* law and *Ampère's law* is that in *Ampère's law* a symmetric (Amperian) loop is considered along the straight line of the charges. In other words, *Ampere's law* is used for symmetrical distribution of currents, while *Biot-savart's law* is used for symmetrical and asymmetrical distribution of currents.

The acting force on conducting wires placed in a magnetic field

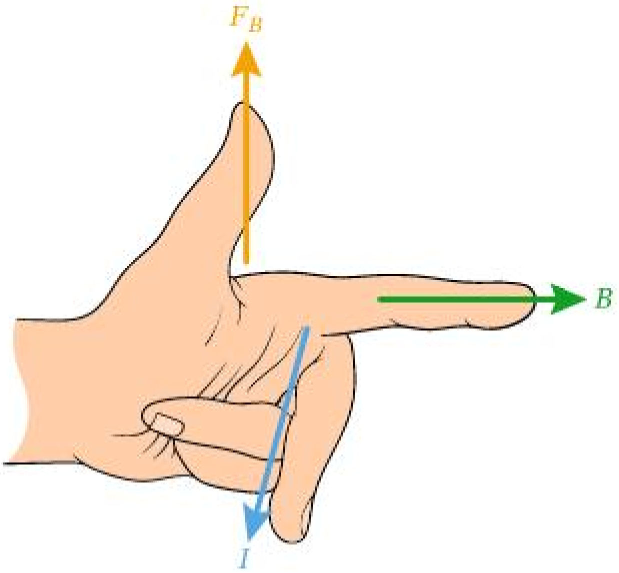
We use the relation $F = BIL$ to calculate the force on a current-carrying wire in a uniform magnetic field.
Magnets don't just force each other. Rather, it can also have a strong effect on the wire. We assume that we place a wire between two magnets, so that the wire is inside the magnetic field, as in the following figure.



If the wire is not carrying current, then there is no force, but if a current is passing through the wire perpendicular to the direction of a uniform magnetic field, then the magnetic field acts on the wire with the force F_B which we get from the equation:

$$F_B=BIL$$

We can determine the direction of the force using Fleming's left-hand rule. With your left hand, extend your index finger forward, point your thumb up, and move your middle finger to become perpendicular to your thumb, as shown in the following figure.



The index finger represents the direction of the magnetic field, *B*, the middle one the direction of the electric current, *I*, and the thumb the direction of the force on the wire, *F* .

As the angle between the magnetic field and the electric current approaches 90 degrees, the force on the wire increases. The value of this force gradually decreases until it reaches zero when the magnetic field and current are parallel, or have an angle of 0 degrees between them, as shown in the following figure.

The magnetic field created by an electric current

An electric current in a wire is capable of generating a magnetic field. Oersted's experiment was the first empirical demonstration that electric and magnetic phenomena are closely related to each other.

We study two of the laws that deal with this subject. The first law is called "Ampere's Law" and the second law is "Biot Savart Law") Laplace-Ampere rule.
These two laws correspond to two laws: Coulomb's law and Gauss's law for calculating the electric field.

Ampere's Law

Ampère's law is a formulation of the relationship between the current and the magnetic field arising from it in its integral form. This law states that "the line integral of magnetic induction around a closed path is equal to the sum of the currents within this path multiplied by the vacuum permeability coefficient μ_o", meaning that:

$$\oint_C \vec{B}.\vec{dl} = \oint_C B\cos\theta\, dl = \mu_o \sum I$$

Where *dl* is the length component of the closed path, θ is the angle between *dl*, B. In the case of more than one current inside the closed path.

In the case of a single current, this equation can be written in the following form:

$$\oint_C \vec{B}.\vec{dl} = \mu_o I$$

Applications of Ampère's Law

1. **The magnetic field created by an electric current in a straight conductor.**

● **If an electric current ,I, passes through a straight conductor, then the lines of magnetic force around the conductor are circles with the center at the conductor itself.**

If it is considered that one of these circles represents a closed path around the current and the radius of this orbit is r, then the direction of *B* is the direction of *dl* itself, tangent to the lines of force. Applying Ampère's law, we get:

- $B\int_0^{2\pi r} dl = \mu_0 I$
- $B\,2\pi r = \mu_0 I$ **or** $B = \frac{\mu_0}{2\pi}\frac{I}{r}$

2 . The strength of the magnetic field produced by a current in a solenoid.

$$B=\mu n I$$

Magnetism

The science of magnetism arose from the observation that some stones called magnetite Fe3O4 attract particles of iron. The word "Magnetism" is derived from the Magnesia region in Asia Minor, where these stones are located. It is known that the globe itself is a permanent magnet.

In 1820, the scientist Orested noticed that if a current passed through a wire, a magnetic effect would arise, represented by the deflection of a magnetic needle placed next to the wire. Orested's discovery linked a relationship between the science of electricity and the science of magnetism.

properties of magnets

1. Magnets have the ability to attract objects made of magnetic materials (iron, cobalt, nickel, but not wood, paper, cork, and cloth).

2. Every magnet has two poles of equal strength and different types (north and south).The North Pole is denoted by the letter N, and the South Pole is denoted by the letter S).

3. The area in which the attractive force of the magnet is concentrated is called the magnetic pole.

4. If the magnet is cut from any part of it, it will have two poles, and it cannot practically have a single pole.

5. The strength of the magnet is concentrated at each of its poles and decreases gradually until it ceases at its middle. (The region in which the magnetic force is absent is called the inertia region).

6 . The straight line joining the poles of a magnet is called the axis of the magnet

7 . Magnetic poles affect each other with a mutual force called the magnetic force.

8. The magnetic force is a repulsive force between similar poles or an attractive force between different poles.

Coulomb's law in magnetism

Practical experiments indicate that the magnetic force between the poles depends on:

1. The distance between the poles (inversely proportional to the square of the distance between them).

2. The intensity of each of the two poles is directly proportional.

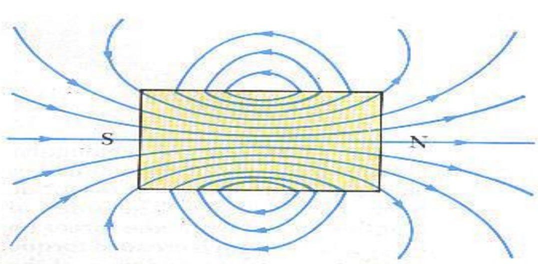
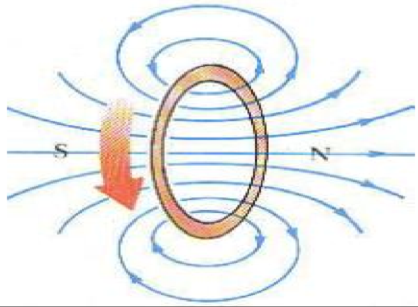
3. The type of medium separating them.

Coulomb's law in magnetism :"*The magnetic force between two poles is directly proportional to the product of the strengths of the poles and inversely proportional to the square of the distance between them*".

Magnetic field

The magnetic field is a physical quantity created around natural magnets and around electric currents or moving charges, enabling it to influence magnetic materials and other electric currents.

The magnetic field is represented by imaginary lines called magnetic field lines, whose direction at any point (or the direction of the tangent to it at that point) indicates the direction of the field at that point...The direction of these lines can be detected practically by using a small magnetic compass needle.

	
Magnetic field lines of permanent magnets	**Magnetic field lines of a current-carrying loop**

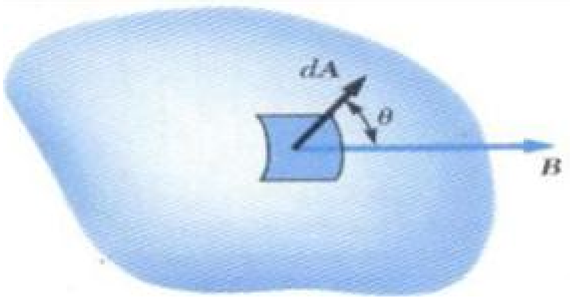
The unit of magnetic field B is "Tesla" and is symbolized by the symbol T, and the Tesla unit is a large unit and a smaller unit known as the "Gauss" can be used as:

$$\text{Tesla} = 10^4 \text{ Gauss}$$

Magnetic Flux

Magnetic flux, also known as electric flux, magnetic flux can be defined as the number of magnetic lines that cross a unit perpendicular area.

Suppose dA is an area component of an irregular surface as in the figure, the magnetic flux is the number of lines which is expressed by the magnetic field strength B multiplied by the perpendicular area dA .



The magnetic flux is denoted by the symbol Φ_m

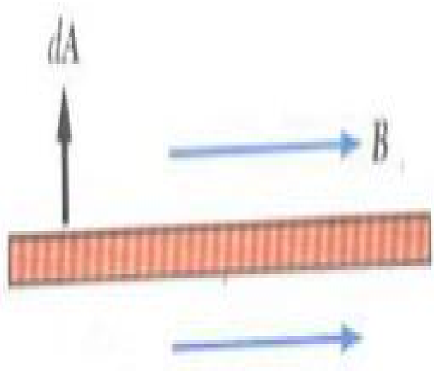
$$\Phi_m = \int B.dA$$

$$\Phi_m = B.A\cos\theta$$

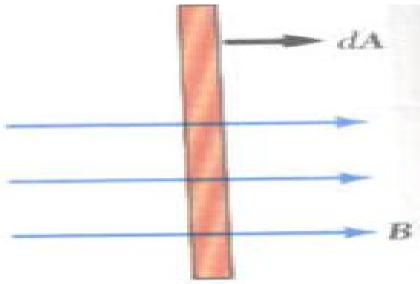
Where dA is the area vector and its value gives the amount of area and its direction is always perpendicular to the area. The unit of magnetic flux is:

$$1\ \text{Wb} = 1\ \text{T.m}^2$$

The value of the magnetic flux is zero if the angle between the magnetic field and the area vector is 90 degrees. This is because in this case there are no magnetic field lines that penetrate the area. In this case the magnetic flux is zero because the vector dA is perpendicular to the field vector B .



The value of the magnetic flux is as large as possible when the angle between the magnetic field and the area vector is 0 or 180 degrees, and here the magnetic flux is either positive or negative. In this case the magnetic flux is equal to BA because the vector dA is in the same direction on the field vector B and the angle involved is zero,



If the magnetic flux is positive, this indicates that the magnetic field lines are in the direction of leaving the surface, but if the magnetic flux sign is negative, this indicates that the magnetic field lines are entering the surface.

Voltage, Current and Resistance

All basic circuits in electricity and electronics are made up of three separate but closely related quantities: Voltage (v), Current (i), and Resistance (Ω).

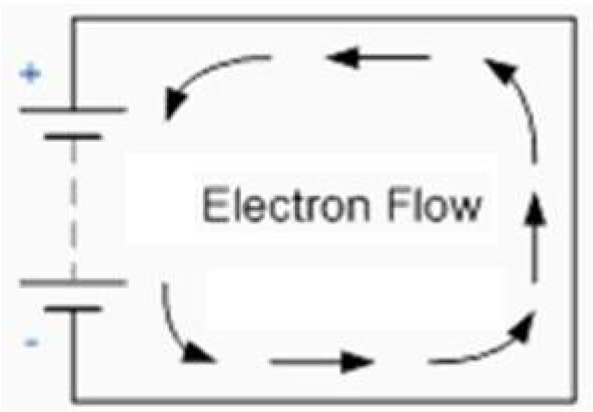
Voltage

It is the potential energy of an electrical source that is stored in the form of an electric charge. Voltage can be seen as a force that pushes electrons through a conductor, at voltage increased, the ability of pushing electrons through a particular circuit is increased. And because energy has the ability to do work, this potential energy can be described as the work required in joules to move electrons in the form of an electric current around the circuit from one point or node (the meeting point of several paths) to another.

The difference in voltage between any two nodes in a circuit is known as the Potential Difference (P.D.). Sometimes called "Voltage Drop". The source of constant voltage is called "continuous voltage" DC, while the voltage that changes periodically with time is called "alternating or variable voltage."

Electrical Current

Electrical current in the circuit is the time rate of the passage of electrons that flow from the negative pole of the battery (cathode) and return to the positive pole of the battery (the anode). This is because the movement of the electron is opposite to the direction of the electric field that emanates from the positive charge to flow into the negative charge. The flow of electrons is called "Electronic Current flow". As a result, electrons flow from the negative side to the positive side.



Current is measured in ,Amperes, are defined as the number of electrons or charges, Q, in coulombs, that pass through a specific point in the circuit per second.

$$I\,(Amp) = Q(C) / t(s)$$

Generally, current is expressed in microamperes ($\mu A=10^{-6}\ A$) and milliamps ($mA = 10^{-3}A$). The current can be positive or negative. The current that flows in one direction

is called *Direct Current* or *D.C.* ,current that changes (reverberates) back and forth through the circuit is known as *Alternating Current* or *A.C.* .Whether the current is continuous or alternating, it flows in the circuit only when a voltage source is connected to the circuit.

Consequence alternating currents (and voltages) are periodic and change with time, they are expressed in the "effective value" -which is the Root Mean Squared "RMS", symbolized by I_{rms}.

The electric current density

***Electric current density*, *J*, is a measure of the "electrical current strength". It is defined as a vector quantity is measured by the value of the electric current passing through a unit surface. electric current density is measured in Amperes per m^2.**

$$I = \vec{J} \cdot \vec{A}$$

Both the electric current density J and the electric field E are generated within conductor as long as there is an electric potential difference applied to the ends of the conductor. If the electric potential difference is constant, then the electric current is also constant. Also, the electric current density is directly proportional to the electric field strength.

$$J = \sigma E$$

Where *σ* is the constant of proportionality and is called the conductivity of the conductor.

Electrical Resistance

Electrical resistance **of an object is a measure of its opposition to the flow of electric current. Its reciprocal quantity is "*electrical conductance*", measuring the ease with which an electric current passes. The SI unit of electrical resistance is the ohm (*Ω*), while electrical conductance is measured in siemens (*S*) (formerly called the '*mho*' and then represented by (*℧*).**

Ohm's Law

Charges move within a matter in the form of an electric current under the influence of an electric field within the matter. Suppose a matter of cross-sectional area *A* carries an electric current *I*, current density *J*- is defined as the electric current per unit area where:

$$I = nqAv \quad \text{........(1)}$$

$$J = I/A = nqv \quad \text{.........(2)}$$

where *n* is the electron concentration and *v* is the velocity of the electrons.

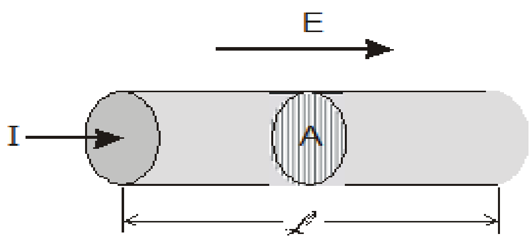
Also, the electric current density is directly proportional to the electric field strength

$$J = \sigma E \quad ....(3)$$

Where ***σ*** **is the constant of proportionality and is called the conductivity of matter. And materials that are subject to this equation say that they fulfill Ohm's law.**

Materials that satisfy Ohm's law that (electric field and electric current are directly proportional) are called ***ohmic materials*****. Ohmic and materials that do not satisfy Ohm's law are called** ***nonohmic*****.**

Suppose we have a conductor of length ***L*** **and cross-sectional area** ***A*** **as in the figure below. If an electric potential difference is applied to both ends of the wire, an electric field** ***E*** **will arise in the conductor:**



Since the relationship between the electric field and the electric potential difference is:

$$V = E\,l \quad ....(4)$$

We can express the electric current density passing through the conductor as:

$$J = \sigma E = \sigma \frac{V}{l} \quad \text{..........(5)}$$

Because it is $$J = \frac{I}{A}$$

$$V = J \frac{l}{\sigma} = [\frac{l}{\sigma A}] I \quad \text{........(6)}$$

The value [l/σA] is called the resistance of matter.

$$R = \frac{l}{\sigma A} = \frac{V}{I} \quad \text{.........(7)}$$

We find from the last equation that the resistance *R* has a unit of Volt/Amp and is called ohm and is symbolized by the symbol *Ω*.

Resistivity

The reciprocal of conductivity is called the resistivity of the conductor

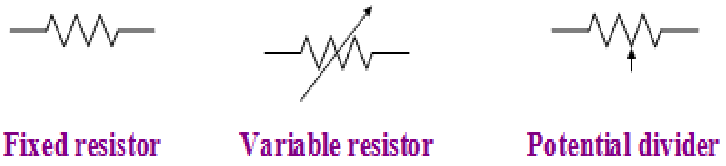
$$\rho = \frac{1}{\sigma}$$

Thus, the resistance of the conductor can be expressed in terms of the specific resistance as follows:

$$R = \rho \frac{l}{A}$$

Where ρ is the resistivity of the conductor and is measured in (Ωm).From the previous equation, we conclude that the resistance of a conductor is directly proportional to its length and inversely proportional to its cross-sectional

area, and all electrical circuits use resistance as a major part of the circuit. The resistance is drawn as shown in the following figure:



There are two types of electrical resistors, the first type is a carbon resistance and the second type is a wire in the form of a coil. The calculation of the resistance value is based on colored rings, and each color symbolizes a value from which we can calculate the resistance value, and the following figure shows that.

carbon resistance

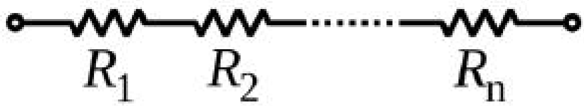
Connect resistors

Connecting resistors in series

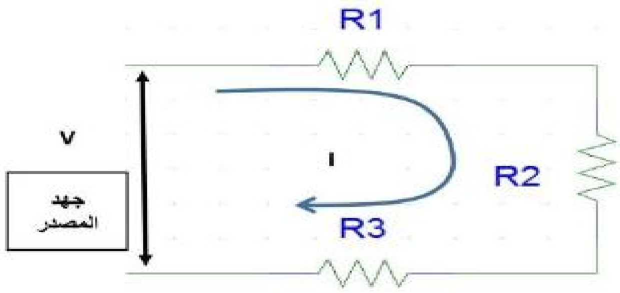
Series connection is the method of connecting the electrical parts (resistors and capacitors.....) in a circuit so that there is one current passing through all parts of the circuit in sequence. The total voltage applied to the circuit is equal to the algebraic sum of the voltages on each resistance, meaning that

$$I = I_1 = I_2 = I_n$$

$$V = V_1 + V_2 + \dots\dots\dots.. + V_n$$



To find the equivalent resistance of three resistors connected in series with a voltage source as shown in the figure



We take the algebraic sum of the changes in the voltage across the closed circuit in the direction of the current

$$V - IR_1 - IR_2 - IR_3 = 0$$

$$V = I(R_1 + R_2 + R_3)$$

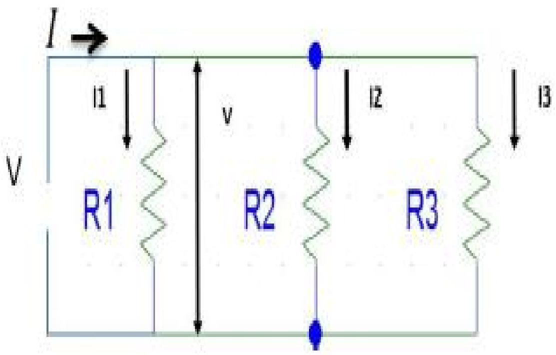
So the equivalent resistance (of the three resistors is the algebraic sum of the three resistors, ie

$$R_e = R_1 + R_2 + R_3$$

Connecting resistors in parallel

Connection in parallel is a method of connecting electrical parts (resistors and capacitors) so that the voltage is the same and equal to the voltage of the source, while the distribution of current on the resistors is according to its value, where the value of the current is inversely

proportional to the value of the resistance passing through it.



$$I = I_1 + I_2 + I_3$$

$$V = V_1 = V_2 = V_3$$

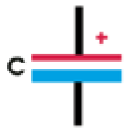
$$I_1 = \frac{V}{R_1}\ ,\ I_2 = \frac{V}{R_2}\ , I_3 = \frac{V}{R_3}$$

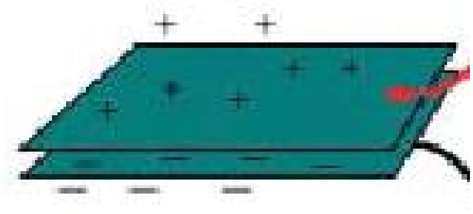
$$\frac{V}{R_e} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{1}{R_e} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

Electrical Capacitors

Capacitors generally consist of two adjacent conductive plates isolated from each other, each of which carries two charges of equal amount and different in sign. The charging process takes place by connecting them to a battery for a short period. The types of capacitors are determined according to their capacity, which is measured in farads.





Electrical Capacitance

Electrical capacitance **of a conductor is defined as the ratio of the amount of charge carried by the conductor to its electric potential.**

Its unit of measurement according to the SI system is (c / v), which is equal to *Farad*, and the energy stored in the capacitor:

$$E_C = \frac{1}{2C} q^2$$

$$1 \text{ F} = 1 \text{ C}^2/\text{J}.$$

The charge *Q* carried by the conductor is directly proportional to its electric potential *V*, that is, the charge placed on the conductor can be increased by increasing the electric voltage ($Q = C\,V$), noting that the continuous increase leads to the occurrence of the phenomenon of electric discharge, as is the case when pumping gas into a container of constant volume ,where increased pumping leads to the explosion of the container. The amount of increase in charge depends on

several factors such as the shape of the conductor, its size, voltage and electrical capacity.

Types of electrical capacitors

Capacitors can be classified according to their value into:

******Fixed capacitors***: Capacitors with a fixed capacity according to the manufacturer.**

- **The type of Fixed capacitor is determined according to the insulating material used in its manufacture.**

- **If the insulating material between the two plates of the capacitor is air, then the capacitor in this case is called *the air capacitor*.**

- **If it is made of plastic, it is called *a plastic capacitor*.**

- **If the insulating material is made of mica, the capacitor is called *a mica capacitor*.**

- **If the dielectric material is ceramic, the capacitor is called *a ceramic capacitor*.**

- **But if a chemical solution is used as an insulating material between the plates of the capacitor, the capacitor is called *the chemical or electrolytic capacitor.***

* *Capacitors with variable value*: - Different capacities can be obtained from them, and they are capacitors whose capacity can be changed and are often used in communication devices that require a limited capacity that may not be available or require a change in frequency when needed, as is the case in radio equipment, where the capacitor changes the tuning of the required stations. It is symbolized by:

- Electrical capacitors can be classified according to their shape into:

1- Electrical capacitor with two parallel plates

$$C = \frac{q}{V} = \varepsilon_o \frac{A}{d}$$

The electric field between the two plates is uniform (except for the two ends), meaning that the lines of electric force are parallel and equidistant from each other.

2- The cylindrical capacitor

$$C = \frac{q}{V} = \frac{2\pi\varepsilon_0 l}{\ln\frac{b}{a}}$$

whereas :
l = the length of the axis of the cylinder.
a = the radius of the inner cylinder.
b = radius of the outer cylinder.

3- Spherical electrical capacitor

$$C = \frac{q}{V} = \frac{4\pi\varepsilon_0 ab}{b-a}$$

a = the radius of the inner Sphere.
b = radius of the outer Sphere.

4- A capacitor with two wires of two parallel lengths

$$C = \frac{q}{V} = \frac{\pi \mathcal{E}_0 l}{\ln \frac{d}{r}}$$

whereas :
l **= the length of the two wires**
d **= distance between the two wires.**
r **= radius of the wire.**

The importance of using insulating material

1- The plates gain durability and are less susceptible to damage.
2- The capacitor is less susceptible to electrical breakdown.

3- Because the dielectric strength of insulators is greater than that of air, which increases their tolerance to voltages. For example, the dielectric strength of air is 800 v/m, for paper 1400 v/m, for mica 1600 v/m.

4 - The value of electrical capacitance increases by the dielectric constant of the insulating material.

Affecting Factors the capacitance of a capacitor

According to the equation below, there are three main factors that directly affect the capacitance of a capacitor. These factors are:

$$C = \mathcal{E}_o \frac{A}{d}$$

■ ***Surface area of capacitor plates*** **(*A*):**

The capacity of the capacitor is directly proportional to the surface area of the plates. If the surface area of the plate increases, the capacitance of the capacitor increases in order to increase its absorption of electric charges. Conversely, the capacitance of the capacitor decreases as this area decreases.

■ ***The distance between the capacitor plates*** (***d***):

The capacitance decreases when the distance between the plates increases and increases as that distance decreases, that is, there is an inverse proportion between the capacitance of the capacitor and the distance between its plates.

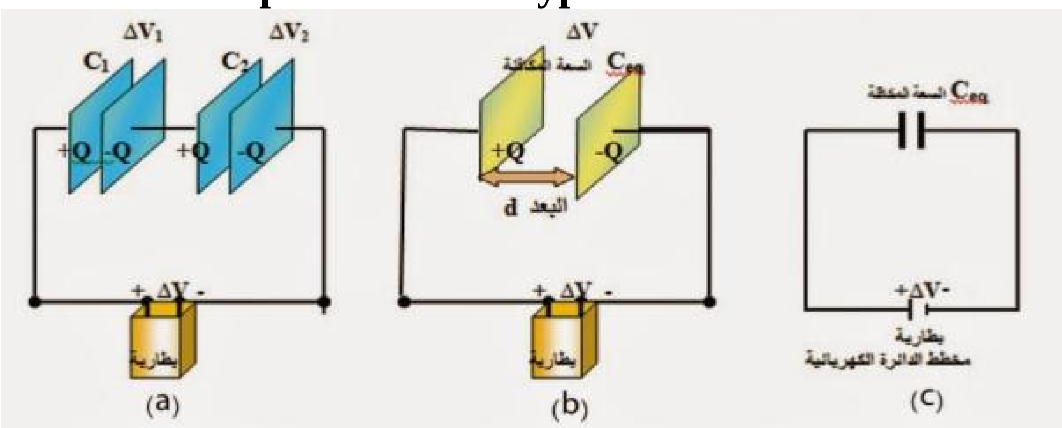
■***The dielectric constant*** (***ε***) ***of the insulating material***:

The capacity of the capacitor changes with the change of the insulating material between the plates of the capacitor as a result of the change of the dielectric constant, as each material has its own dielectric constant, and air is the basic unit for comparing the ability to isolate other materials used in the manufacture of capacitors. The dielectric constant (*ε*) is called the upsilon.

Methods for connecting electrical capacitors

1-Series Connection

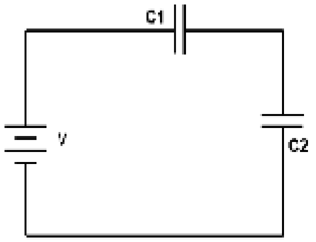
This connection is characterized by the stability of the charge and the equivalent capacitance decreases as a result of the increase in the distance between the two plates of equivalent electrical capacitance with the stability of the area of the two plates and the type of insulator.



$$C_1 = \frac{Q}{\Delta V_1}$$

$$C_2 = \frac{Q}{\Delta V_2}$$

$$C_{eq} = \frac{Q}{\Delta V_{total}}$$



$$\Delta V_{total} = \Delta V_1 + \Delta V_2$$

$$\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

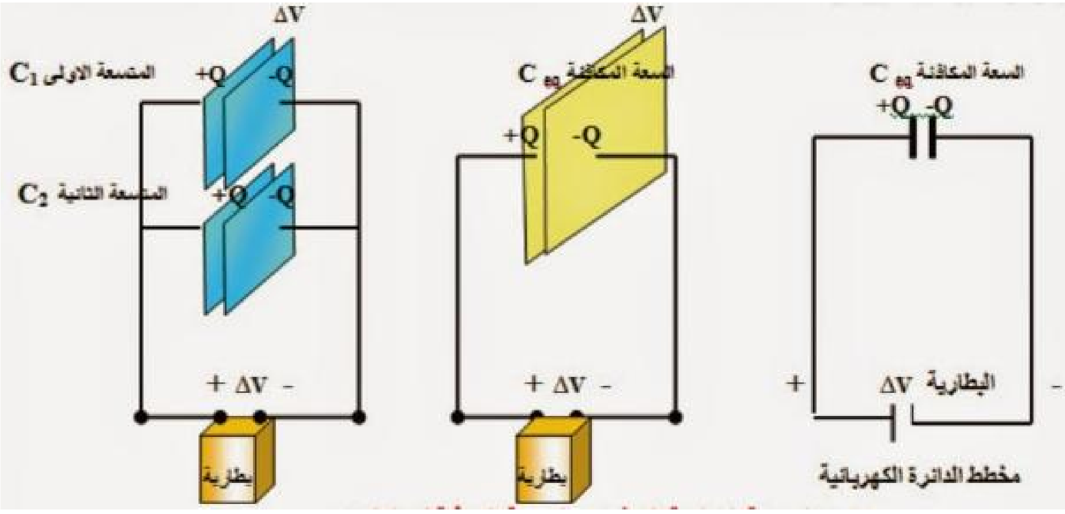
$$\frac{Q}{C_{eq}} = Q\left[\frac{1}{C_1} + \frac{1}{C_2}\right]$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

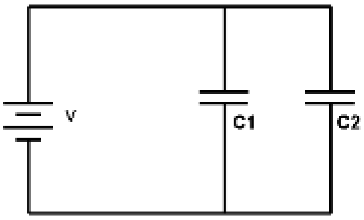
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots\ldots\ldots \frac{1}{C_n}$$

2-Parallel Connection

This connection is characterized by the stability of the voltage and the equivalent capacitance increases as a result of the increase in the surface area of the two plates of equivalent capacitance with the stability of the distance between the two plates of and the type of insulator.



$$\Delta V_1 = \Delta V_2 = \Delta V_{battery} = \Delta V$$



$$Q_1 = C_1 \Delta V$$

$$Q_2 = C_2 \Delta V$$

$$Q_{total} = C_{eq} \times \Delta V$$

$$Q_{total} = Q_1 + Q_2$$

$$C_{eq} \times \Delta V = C_1 \Delta V + C_2 \Delta V$$

$$C_{eq} \times \Delta V = \Delta V \left[C_1 + C_2 \right]$$

$$C_{eq} = C_1 + C_2$$

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots\ldots C_n$$

Electric Potential Energy

The potential energy **of a group of point charges is known as the work that must be done to collect these charges by bringing each charge from infinity.**

We assume that the charges are at rest and when they are at infinite distances from each other, the energy can be calculated for a group of two charges, q_2 and q_1. Moving the charge q_1 from infinity and placing it in a place does not require doing work.

$$W_1 = 0$$

But moving the charge q_2 from infinity and placing it at a distance r from q_1 requires doing work of:

$$W_2 = q_2 V_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

Where V_1 represents the electric potential of charge q_1 at a distance r

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r}$$

$$W_2 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

$$W = W_1 + W_2 = 0 + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r} \quad \ldots\ldots\ldots\ldots(14)$$

It is the same as the potential energy for a point charge

$$E_P = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

Voltage is the potential energy per unit charge

$$E_P = q_o V_{AB}$$

Electrical Potential and Potential Energy for Charge Point

In the same way, we can calculate the potential energy of a group consisting of three charges.

$$W_1 = 0$$
$$W_2 = q_2 V_1$$
$$W_2 = \frac{1}{4pe_o}\frac{q_1 q_2}{r_{12}}$$
$$W_3 = q_3 V_1 + q_3 V_2$$
$$W_3 = \frac{1}{4pe_o}\frac{q_1 q_3}{r_{13}} + \frac{1}{4pe_o}\frac{q_2 q_3}{r_{23}}$$

The algebraic sum of the three quantities

$$E_P = W_1 + W_2 + W_3$$
$$E_P = 0 + \frac{1}{4pe_o}\frac{q_1 q_2}{r_{12}} + \frac{1}{4pe_o}\frac{q_1 q_3}{r_{13}} + \frac{1}{4pe_o}\frac{q_2 q_3}{r_{23}}$$
$$E_P = \frac{1}{4pe_o}\left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right]$$

The energy principle

The law of energy conservation applies to the movement of any charged body in an electric field, such as the movement of an electron or an ion.

Every charged partical in an electric field has potential energy resulting from the work done to move it against the electric force.

The work-energy relationship

$$W = \Delta E_K$$

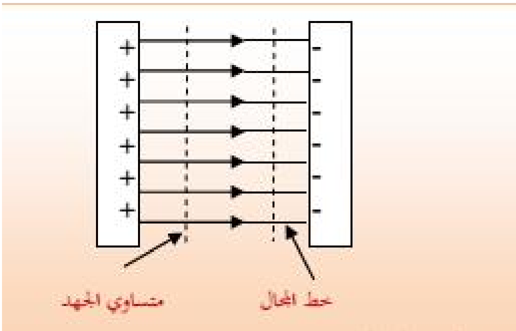
$$q(V_2 - V_1) = \frac{1}{2}mV_2^2 + \frac{1}{2}mV_1^2 \qquad \text{............(15)}$$

Equipotential Surface

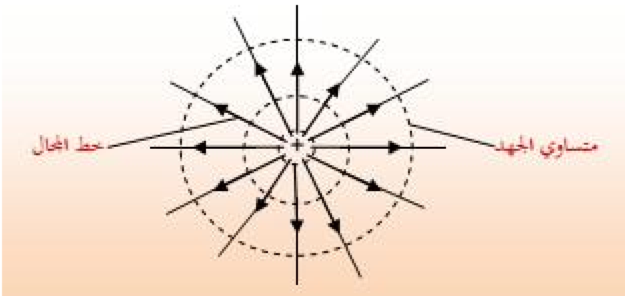
A surface in which all points are of equal potential. These surfaces are perpendicular to the electric field strength E, meaning that these surfaces are perpendicular to the electric field lines.

- **The work required to move a test charge between two points on equipotential surfaces must be zero.**

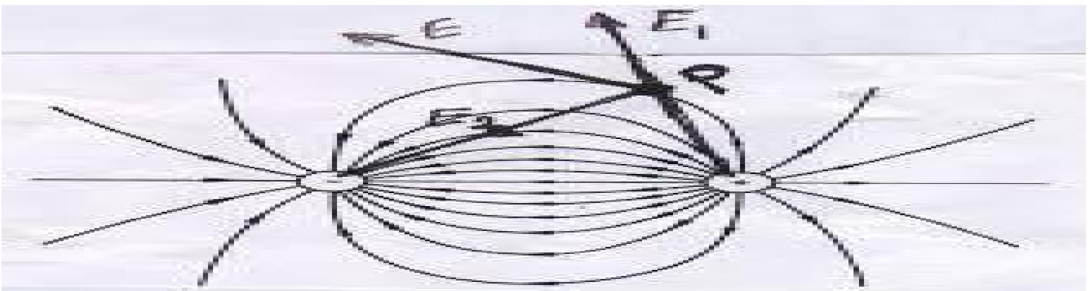
The figure shows two parallel plates between which the electric field is uniform. Equipotential surfaces are flat and parallel



In the figure below, it represents a field created by a positive point charge, Concentric spherical equipotential surfaces.



The equipotential surfaces of a dipole are represented by the figure below



The equipotential surfaces are *crowded* and *close* to each other in the region where *the field is strong*. While the equipotential surfaces are *far apart* in the region where *the field is weak*.

Characteristics of equipotential surfaces

1. All points of the same surface are of the same voltage.

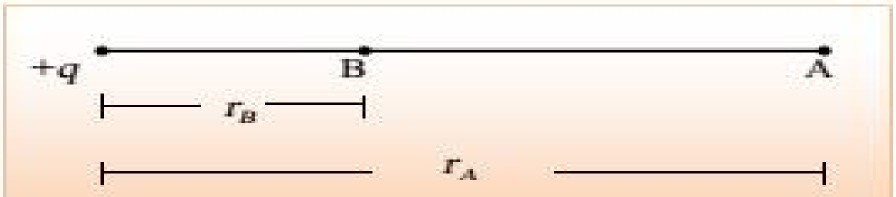
2. Transferring the charge between the points of the same surface does not require the completion of work.

3. Lines of the electric force act vertically on the equipotential surface.

4. Equipotential surfaces do not intersect with each other.

Electrical Potential for Charge Point

To find the amount of electric potential in a point such as B located near a point charge, we first find a relationship for the potential difference between points A and B located in the electric field of the positive charge (*+q*) at the distances r_A and r_B respectively as shown in Figure (2).



Equation (4) is used to calculate the potential difference between points A and B:

$$V_B - V_A = -\int_A^B E\cos q\,dr$$

$$\vec{E} = \frac{1}{4pe_0}\frac{q\,\hat{r}}{r^2}$$

E **represents the electric field strength at a point in the space surrounding charge (*+q*) and away from it *r***

$$\therefore V_B - V_A = -\frac{1}{4pe_0}\int_{r_A}^{r_B} q\cos q\,\frac{dr}{r^2}$$

$$V_B - V_A = -\frac{1}{4pe_0}\int_{r_A}^{r_B} q\cos 0\,\frac{dr}{r^2}$$

$$V_B - V_A = -\frac{q}{4pe_0}\int_{r_A}^{r_B}\frac{dr}{r^2} = -\frac{q}{4pe_0}\left[-\frac{1}{r}\right]_{r_A}^{r_B}$$

$$V_B - V_A = \frac{q}{4pe_0}\left[\frac{1}{r_B} - \frac{1}{r_A}\right] \qquad \text{.........(7)}$$

Now if the position of point A (or B) is made at infinity or very far from charge (*q*), then ($r_A = \infty$) or ($r_B = \infty$) becomes ($V_A = \infty$) or ($V_B = \infty$) and by substituting these values for r_A and r_B into Equation (7) we obtain the value of the absolute voltage at point B (or A). For any point at a distance *r* in the field of charge (*q*), we get:

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \qquad \text{........(8)}$$

Electrical Potential for Groups Charges Point

To find the voltage for a group of point charges q_1, q_2, ... q_n, which are at distances r_1, r_2, and..... r_n from a point such as p located in its electric field, calculate V_1, V_2, ... V_n each charge separately at point p as if the other charges were not present, i.e.:

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1}, \quad V_2 = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$$

Thus, the total voltage is the algebraic sum of the individual contributions. Once again, this is the principle of superposition, but here it is using scalar quantities and in the following form:

$$V = V_1 + V_2 + \dots\dots\dots\dots + V_n = \sum_n V_n$$

$$\therefore V = \frac{1}{4\pi\varepsilon_0}\sum_n \frac{q}{r_n} \qquad \text{..........(9)}$$

where r_n is the distances at which the charges q_n are from the point under consideration.

Electric potential of connected charges

When the charge is distributed in a continuous distribution, such as the charge is distributed on the surface of a conductive body or distributed within a certain volume in a continuous manner, then the voltage arising from it can be found by dividing the charge into a large number of differential elements dq and then calculating the voltage dV arising from each element of dq at a point far away r for the differential element, ie:

$$dV = \frac{1}{4pe_0}\frac{dq}{r} \qquad \text{..........(10)}$$

In order to find the total voltage arising from the entire charge, the integration process is carried out for all the voltages arising from the differential parts, i.e.:

$$V = \int dV = \frac{1}{4pe_0}\int \frac{dq}{r} \qquad \text{.......... (11)}$$

Difference Potential

It is the work done to move a unit charge between two points in an electric field

$$V_B - V_A = \frac{W_{AB}}{q_0} = \frac{-\int_A^B q_0 E \cos q dr}{q_0}$$

$$V_B - V_A = -\int_A^B E \cos q dr$$

Where V_A and V_B are the voltages at points A and B respectively, point B represents a higher voltage than point A. Like a battery, it has two poles. We denote the high voltage pole with a sign (+) and the low voltage (-). We will denote the voltage difference between two points, such as B, A, with the symbol V_{AB} .

$$V_{AB} = V_A - V_B$$

If the difference is positive, it indicates that point A is at a higher voltage than point B, so external work must be done to transfer a positive charge from point B to point A. If the difference is negative, then point B is at a higher voltage than point A. The work will be done by the field when the positive charge is allowed to move from A to B.

$$V_{AB} = V_A - V_B$$

$$V_{BA} = V_B - V_A = - V_A + V_B$$
$$V_{BA} = - (V_A - V_B)$$
$$V_{BA} = - V_{AB} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Gauss's law

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

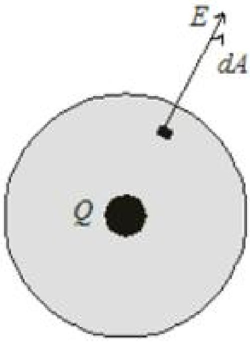
Gauss's law states that *"the net flux through any closed Gaussian surface* is equal to: *the net electric charge* inside the surface divided by *the vacuum permittivity"*.

$$\varnothing = \oint \vec{E} \, .\overrightarrow{dA} = \frac{q_{in}}{\varepsilon_0} = \frac{(q1 + q2 + q3 + ...+qn)}{\varepsilon_0}$$

***Closed surface*: It is a compressed and unlimited surface, in the sense that it divides the space - *with the exception of itself* - into an *external* and *an internal* part. Examples of closed surfaces are perfect bubbles, *Dyson spheres*, or the filed in which the object will be.**

To calculate the electric flux produced by an electric charge

We assume that there is a spherical surface surrounding the charge called *a Gaussian surface*, and the flux is equal to:



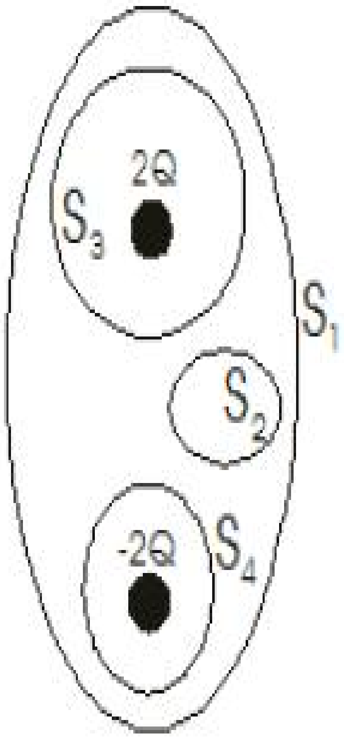
$$\Phi = \oint \vec{E}.\overrightarrow{dA} = E \oint dA \cos\theta = E \oint dA \cos 0$$

$$\Phi = \frac{q}{4\pi\epsilon_o r^2} \oint dA = \frac{q}{4\pi\epsilon_o r^2} 4\pi r^2 = \frac{q}{\epsilon_o}$$

.

It is noted that *the electric flux* through a Causs surface is proportional to *the charge inside* the surface.

Example 1 :In the figure below, calculate the total flux (Ø) of the surfaces: S_1, S_2, S_3 & S_4



For S_1 the flux F = zero

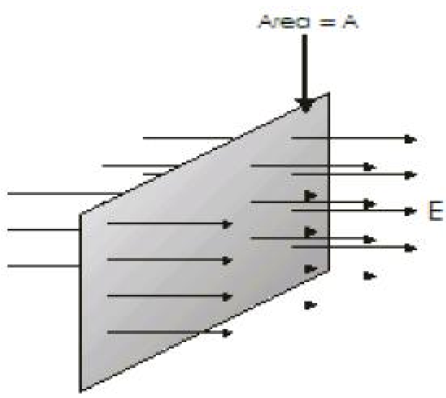
For S_2 the flux F = zer

For S_3 the flux F = $+2Q/e_o$

For S_4 the flux F = $-2Q/e_o$

To calculate the electric flux produced by an electric field

The first case: *the electric flux* of a plane area perpendicular to a uniform electric field as in the figure، To calculate *the electric flux*, the number of lines is proportional to the value of the electric field. Therefore,

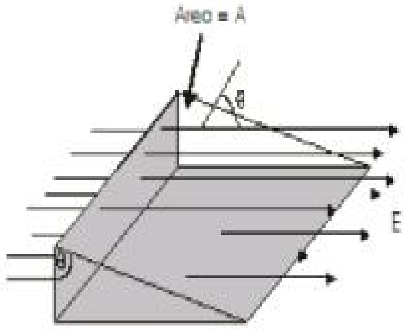


the number of field lines that penetrate the surface of an area is proportional to the magnitude(EA).

So the electric flux is defined as the dot product between the electric field (E) and the surface area (A) perpendicular to the field:

$$\boldsymbol{\Phi} = \vec{E}.\vec{A} \quad \text{……………..(5)}$$

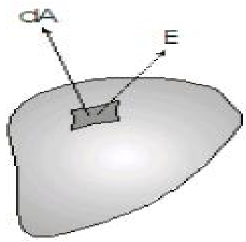
The second case: the electric flux of a surface makes an angle (θ) with a uniform field, as in the figure.



The flux has *a maximum value* when the surface is *perpendicular* to the field, that is, at (θ = 90), and it has *a value of 0* if the surface is *parallel* to (θ = 0).

The third case: the general case, which is if the field is irregular and penetrates an area. The flux is calculated through the formula:

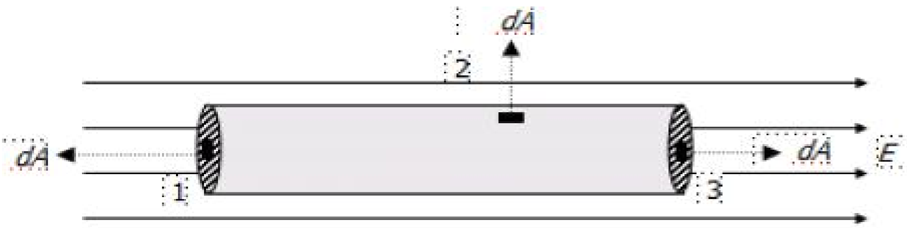
$$\boldsymbol{\Phi} = \oint \vec{E}.\vec{A} \quad \text{……………..(6)}$$



Where the *perpendicular component* of the electric field is taken with respect to *the area*, the *net flux* is proportional to the *net field lines* that *pass through an area*.

.

Example 2: Calculate the *total flux* of a closed cylinder of radius (R) placed in *a uniform electric field*.



We apply *Gauss's law* to the *three surfaces* shown in the figure above:

$$\emptyset = \oint \vec{E}\ .\overline{d\vec{A}} = \oint_{(1)} \vec{E}\ .d\vec{A} + \oint_{(2)} \vec{E}\ .d\vec{A} + \oint_{(3)} \vec{E}\ .\overline{d\vec{A}}$$

$$\emptyset = \oint \vec{E}\ .\overline{d\vec{A}} = \oint_{(1)} E\ dA\cos 180 + \oint_{(2)} E\ dA\ \cos 90 + \oint_{(3)} E\ dA \cos o$$

Since *the electric field* is constant:

(H.W.1): Calculate the total electric flux of a cube in a uniform electric field.

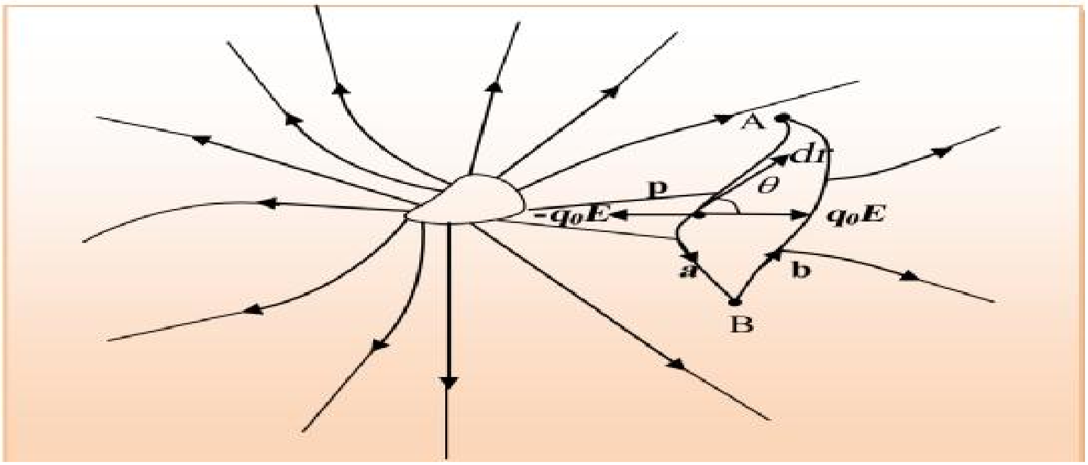
(H.W.2) A cylinder of radius (R) charged with a uniform charge (ρ) Calculate the electric field at a point far (r) from the axis of the cylinder (r<R).

Electric Potential

Voltage Difference and Electric

When an electric charge (+q) is placed in an electric field, the field will act on it with a force of magnitude (qE) and its direction is with the direction of the electric field. If we want to hold this charge in place, we must exert a force of (-qE) on it.

Let's consider a positive test charge(q_o) originally located at point P within a non-uniform electric field, as in Figure (1). When moving it to point B along path a, we have to do work with an external factor against the electric force so that the movement of the charge always remains in equilibrium. The potential difference between points A and B within the electric field is the work done against the electric force to move a unit positive test charge from A to B.



The potential difference between points A and B is defined as the work done (W_{AB})per unit charge, i.e.:

$$V_B - V_A = \frac{W_{AB}}{q_0} \qquad \text{........(1)}$$

The SI units for potential difference are *joules per coulomb*. We will call this derived quantity a *volt* relative to

the Italian scientist *Alessandro Volta* (*1745-1827*). There are parts of this unit that are used to measure *small voltage differences* such as the *millivolt* (*mV*), which is equivalent to *one thousandth* of a volt, and the *microvolt* (*μV*), which *is one millionth* of a volt. *Large voltage* is expressed in *kilovolts* (*KV*), which is equivalent to *one thousand volts*, and *megavolts* (*MV*), which is *one million volts*.

Since *work* is a *numerical quantity*, the *potential difference* is also a *numerical quantity*.

To measure the voltage at any point, it is agreed that the voltage of the points that are *very far from* the charges should be equal to *zero*. If we choose point A in (infinity) the voltage V_A becomes *zero*, and by substituting in equation (1) we get the voltage at point B.

So the definition of voltage at a point *is the work per unit charge that must be done to transfer a positive test charge from (infinity) to that point* (or *from a point of zero potential to the point concerned*) and the mathematical relationship is:

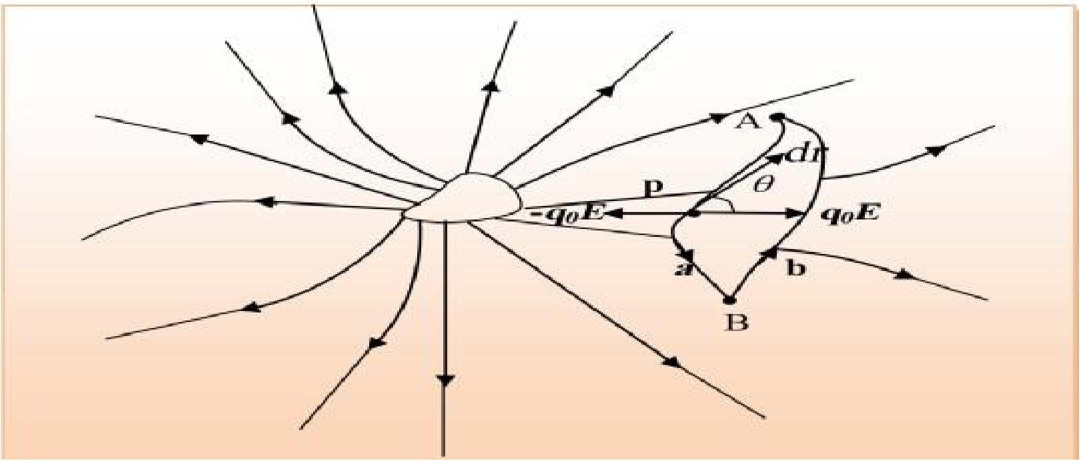
$$V = \frac{W}{q_0} \quad \text{..........(2)}$$

Here it is necessary to point out an important point related to the potential difference, which is to consider the *earth's voltage* equal to *zero* and to take it as *a standard reference* for many electrical circuit issues.

The Relation between Voltage Difference and Field Intensity

To find the relationship between the potential difference V and the field strength E, it is necessary to calculate *the work* that needs to be done by an external factor *to move a positive test charge* (q_o) in an irregular field

and on a wavy path between points A and B without acceleration as in Figure (1).



If we assume that the charge qo moves along the path a without acceleration, then this requires that (q_o) at any point along the path between A and B fall under the influence of two opposite forces:

the first : is imposed by the electric field and its magnitude is (q_oE) and is in the same direction as the field, and

the second : is imposed by an external factor of magnitude ($-q_oE$) and is In the opposite direction of the field, the work done becomes:

$$W_{AB} = -\int_A^B q_0 E \cos q dr$$

Or

$$\frac{W_{AB}}{q_0} = -\int_A^B E \cos q dr \qquad \text{..........(3)}$$

where *dr* is a differential displacement on the path a acts an angle *θ* with the direction of the electric field. If we compare equations (1) and (3), we find that the potential difference between points A and B is equal to:

$$V_B - V_A = -\int_A^B E\cos q dr$$ ....(4)

By connecting equations (3) and (4), we get:

$$V_B - V_A = \frac{W_{AB}}{q_0}$$

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$$V_B - V_A = \frac{\Delta(p.E)}{q_0}$$ ....(5)

That is, the amount of work done on this charge(q_o) is equal to the change in its potential energy (*P.E*).

In special cases where the field is uniform and parallel to the path of the charge, the movement of the charge in a direction opposite to the field strength makes the angle θ between *E* and *dr* equal to 180^o, and equation (4) becomes as follows:

$$V_B - V_A = -\int_A^B E\cos 180 dr = E\int_A^B dr = Ed$$ ....(6)

As *d* represents the length of the path between points A and B. It appears from equation (6) that the electric field strength can be expressed in units (volts / meters).

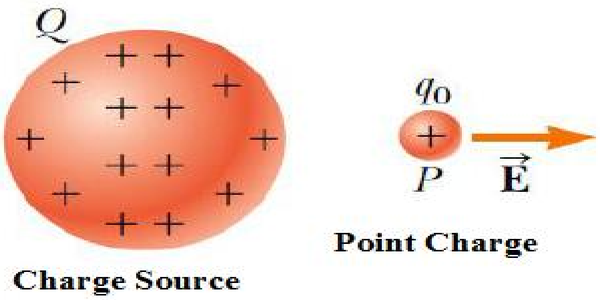
H.W.: Match the unit (volt/meter) to the unit (newton/coulomb).

The Electric Field

The electric field **created by the large charge at the position of the test charge is defined as the electric force acting on the test charge per unit charge or more specifically that the electric field vector ($\vec{E}$)at a point in space is defined as *the electric force* ($\vec{F_e}$) acting on *the charge Test positive* placed at the point divided by *the test charge*.**

$$\vec{E} = \frac{\vec{F_e}}{q_o} \ldots\ldots\ldots\ldots\ldots (1)$$

The vector ($\vec{E}$) has a unit in the (SI) system of (Newton per Coulomb (N/C)), the direction of the field ($\vec{E}$) as shown in the following figure is the direction of the electric force ($\vec{F_e}$) to which the test charge is subjected in the field.



Equation (1) can be rewritten as:

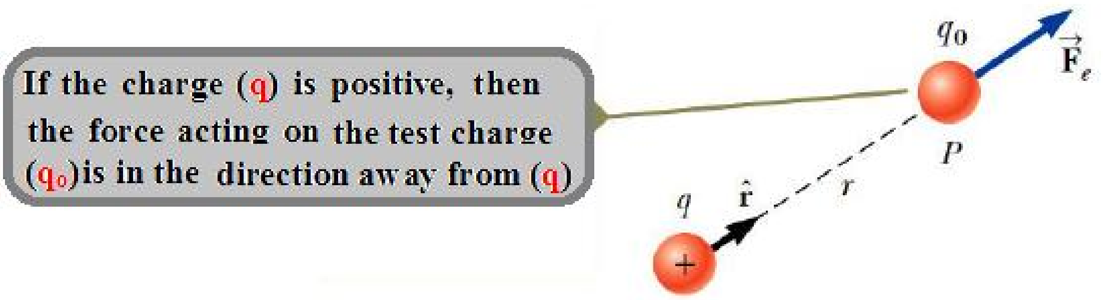
$$\vec{F} = q\vec{E} \ldots\ldots\ldots\ldots\ldots (2)$$

This equation shows the *force acting* on a *charged particle* (q) placed in an electric field. If the charge is *positive*(+q), the electric force is in *the same direction of the electric field*. But if the charge is *negative*(-q), *the electric force and the electric field are in opposite directions*.

Notice: the great similarity between *the electric field equation* $(\vec{F} = q\vec{E})$ and *the Earth's gravitational field equation* $(\vec{F} = m\vec{g})$. Once we know the magnitude and direction of *the electric field* at a particular point, *the electric force exerted* on any charged particle placed at that point can be calculate from equation (2).

According to *Coulomb's law*, *the force exerted* by (q) on *the test charge* is:

Where $\hat{r}$ is a unit vector and directs from (q) to (q_o) this force shown in the following figure:



If the charge (q) is positive, then *the force acting* on *the test charge* (q_o) is in *the direction away from* (q). Because the electric field at point P (where the test charge is located) is defined as: $(\vec{F} = q\vec{E})$, so the electric field at point P resulting from charge (q) is given by the formula:

$$\vec{E_e} = k_e \frac{q_o}{r^2}\hat{r} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

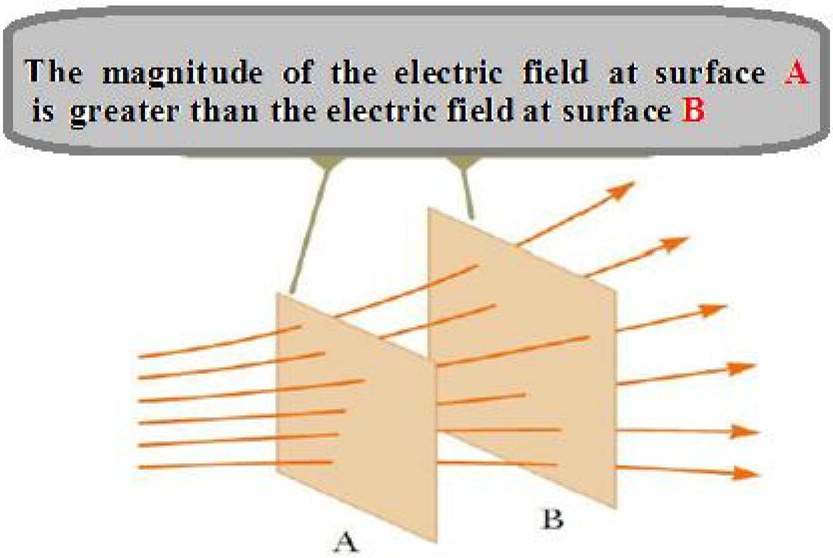
Electric Field Lines

To describe *the electric field*, it is done by *drawing lines* known as *electric field lines*, and the first

scientist to present the idea (*Faraday*), in the following way:

•**The electric field vector (** $\vec{E}$ **) is** the tangent **to** ***the electric field line*** **at** ***each point,*** **the line has a direction determined by vectors of the same magnitude as** ***the electric field vector,*** **and the direction of the line is in the direction of** ***the force acting*** **on a positive test charge placed in the field.**

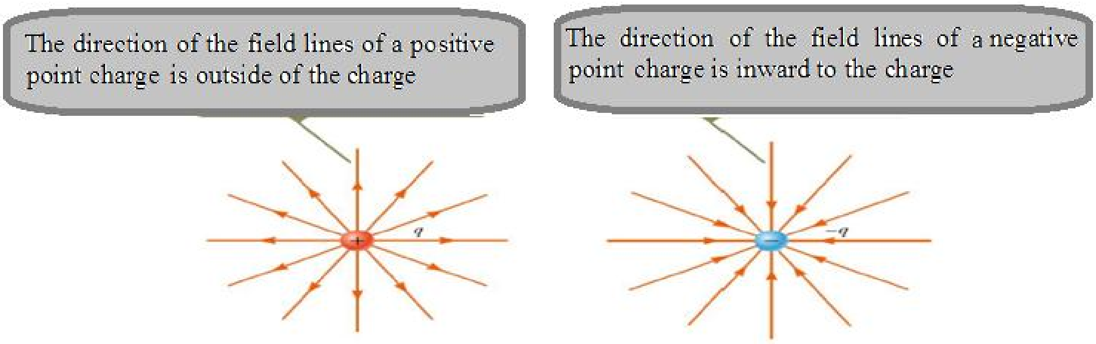
•**The number of lines per unit area passing through a surface area perpendicular to the field lines is directly proportional to the magnitude of the electric field in that area. As** ***the electric field lines*** **are** ***closer to each other*** **when** ***the electric field*** **is** ***strong*** **and** ***the electric field lines*** **are** ***farther from each other*** **when the electric field is** ***weak*****. These properties are shown in the following figure**



The density of the field lines passing through the surface (A) is greater than the density of the lines passing through the surface (B), so ***the amount of the electric field*** **is** ***greater*** **on the surface (A) than the surface (B), the lines at different locations appear in**

different directions. Therefore, *the electric field* is *not uniform*.

Electric field lines representing the field produced by a positive point charge are shown in the following figure:



Note that: **the field lines become *closer to each other* as they *reach the charge*, which indicates that *the electric field strength increases as we approach* the source of the charge.**

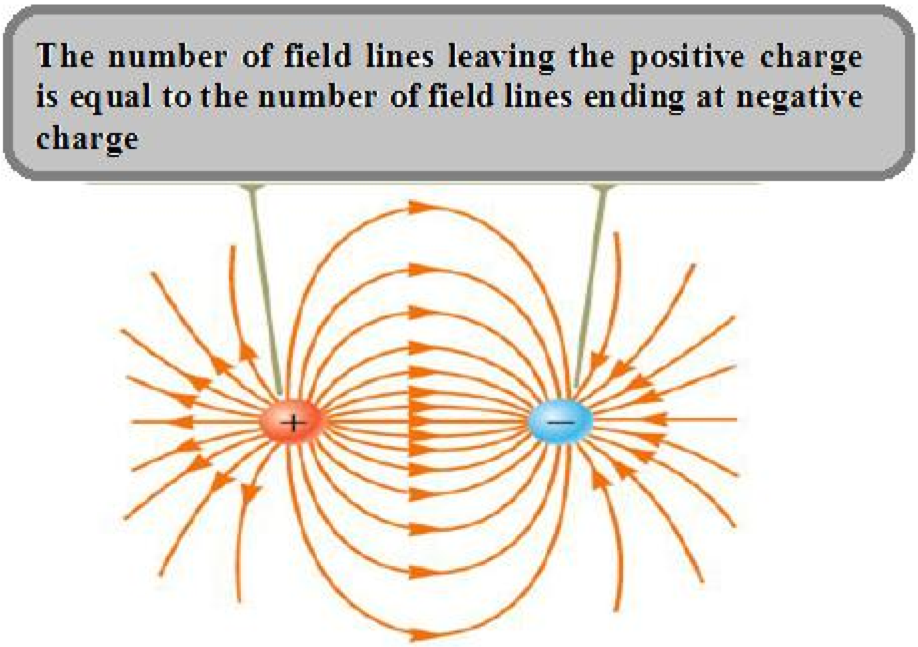
The rules for drawing electric field lines are as follows:

•The electric field lines *start* at *the positive charge* and *end* at *the negative charge*. In the case of only one charge, the field lines begin or end in an infinitely faraway place.

•The number of lines that *leave the positive charge* or *reach the negative charge* is directly proportional to the amount of charge.

• No two electric field lines can intersect.

The number of field lines **leaving** ***the positive charge*** **is equal to** ***the number of field lines*** **ending** ***at negative charge .***



Electric field strength: **An expression of *the number of electric field lines* that traverse perpendicularly per *unit surface area* $\hat{A}$.**

Directional flux (radiative)

We can say that *the electric field flux* through a *surface* is *the value of the electric flux that has passed through it*. We conclude from the following example:

Suppose we put a cloth cover in a tube through which water flows. How much water flows through the cap?

The answer will be: the product of the average vertical component of the velocity by the area of the

cloth cover. This is called: flowing through the cover cloth.

Why do we use the vertical vehicle($\hat{n}$)? Because it is with the direction of flow.

The Electric Flux

Electric flux **(Φ): It is a measure of *the number of electric field lines* that pass through *a given area*. It is the number of electric field lines that vertically traverse an area of a surface.**
Its symbol is (Φ) and its direction is towards the perpendicular to the surface. Its magnitude is *the dot product* of the field vector and *the area vector*$\hat{A}$:

$$\Phi = \vec{E}.\vec{A} = EA\cos\theta \qquad (4)$$

Where (θ) is the angle between *the direction of the electric field* and *the perpendicular to the surface* (*the surface vector*($\hat{n}$)).
To facilitate the calculation of the electric field for a continuous distribution of charge in the form of a longitudinal, surface or volumetric distribution, we use "Gauss's Law". Gauss's law is based mainly on the concept of electric flow resulting from the electric charge or electric field.

Electrostatic Force

Properties of Electric Charges

The text of the law of conservation of charge: -
Charge cannot be Created or Destroyed .

Electric charge is always conserved in an isolated system. That is, when we rub two objects together, the charge formed does not arise out of nowhere. Rather, it results from a state of electrification (the charging process) as a result of the transfer of charge from one body to another.

One object acquires a specific negative charge, while the second object acquires a positive charge of the same amount. For example, when a rod of glass is rubbed with a piece of silk as shown in Figure (1), the silk gets a negative charge equal in amount to the positive charge that formed on the glass rod.

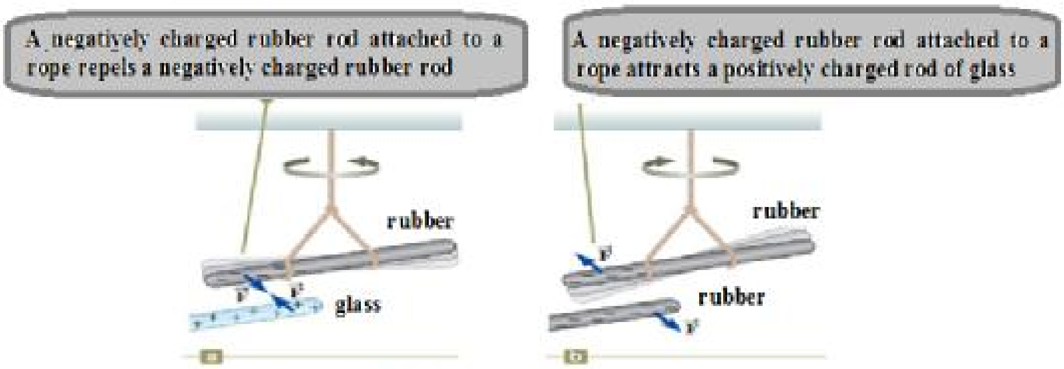


Figure 1: Electrical forces between
(a) Two charged particles with different charges
(b) Two charged particles with similar charges

From the atomic structure, we conclude that electrons are transferred during the rubbing process

from glass to silk. Similarly, when a rubber rod is rubbed into a piece of fur, electrons move from the fur to the rubber, which shows a negative charge on the rubber and a positive charge on the fur. This process occurs because uncharged neutral materials contain a number of positive charges (protons inside the atom nucleus). equal to the number of negative charges (electrons in orbitals surrounding the nucleus).

Type of Charge

1- positive electric charge + protons (*p +*)
2- Negative electric charge - electrons (*e –*)

Electrons have a negative charge (*e-*) and the proton has a positive charge (*e +*) equal to the charge of the electron, but with an opposite sign.

The smallest unit of free charge in nature is the electron charge, e. It is (*–e*) for an electron and (*+e*) for a proton. It has the following value:

$(e = 1.60218 \times 10^{-19}\ C)$.

The charge and mass of each of the electron, proton and neutron are shown in Table (1). Note that the electron and proton are the same in the amount of their charge, but they differ in their mass. On the other hand, both the proton and the neutron have the same mass, but differ in charge.

Table (1): Charge and mass of the electron, proton and neutron

Particle	Mass (kg)	Charge (C)
Electron (e)	9.1094×10^{-31}	$-1.6021765 \times 10^{-19}$
Proton (p)	1.67262×10^{-27}	$+1.6021765 \times 10^{-19}$
Neutron (n)	1.67262×10^{-27}	0

Very important notes

1- The proton is inside the nucleus of the atom and its charge is positive and its magnitude is equal to the magnitude of the charge of the electron.

Matter is made up of atoms, and each atom contains:

(a) - the nucleus and contains positive (p +) protons and neutral neutrons

(b) - Electrons (e-) rotate at a very high speed around the nucleus and have a negative (-) charge.

Note: ***Atoms are electrically neutral when the number of electrons equals the number of protons (the negative charge equals the positive charge)***

2- The charge of an electron or proton is the smallest unit of charge, to measure charges.

3- The charge of any charged body is an integer multiple of the charge of the electron. To calculate the number of electrons for a charged body.

Electric charge (*q*) is quantized, where *q* is the symbol used for charge. This means that the electric charge exists as discrete packets, and we can write that ($q = \pm Ne$), where *N* is an integer.

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4- The amount of charge of an electron

(C is 1.60218×10^{-19}), where (*C*) means a coulomb,and *1*coulomb = 6.25×10^{18} *electrons*.

5- Electron mass = $9.1091 \times^{-31}$ Kg.

6- parts of a coulomb:

millicoulomb ($1\ mC = 10^{-3}\ C$),

microcoulomb ($1 \mu C = 10^{-6}\ C$),

nanocoulomb ($1\ nC = 10^{-9} C$),

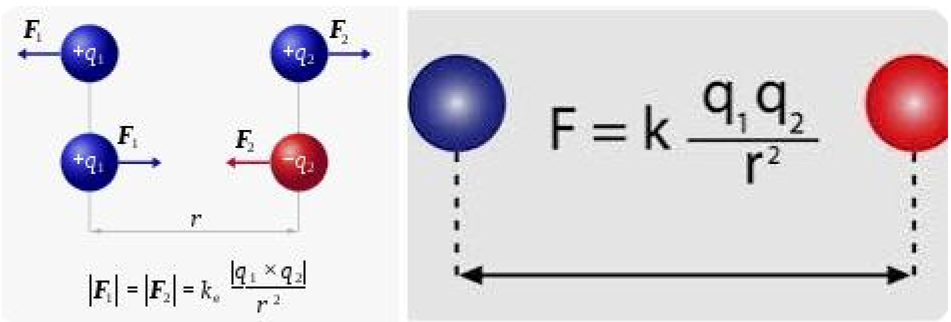
picocoulomb ($1 pC = 10^{-12} C$).

Materials **can be classified according to the ability of their electrons to move within the material:**
Electrical conductors**: are materials that contain free electrons that are not bound to atoms and can move freely within the material.**
Materials such as: copper, aluminum and silver are good conductors of electricity.

Electric Insulator: They are materials in which all electrons are bound with atoms and cannot move freely within the material.
Materials such as: glass, rubber and dry wood.
Semiconductor :is the third class of materials whose electrical properties fall between insulating and conductive materials, such as: silicon and germanium.

Coulomb's Law

The electrical interaction between point charges (a charged particle of zero size) can be studied through an electric force known as the "Electrostatic Force" arising between two stable charged particles through Coulomb's law, which states "*the force of attraction or repulsion between two charges in vacuum is directly proportional to the value absolute net of the product of their charges, and inversely with the square of the distance between them*".



Where (k_e) is a constant known as "*Coulomb's Constant*". Electric forces are conserved forces, just like gravitational forces.

The value of Coulomb's constant depends on the choice of units. The unit of electric charge is the coulomb and it is denoted by the symbol (*C*) and the coulomb constant (k_e) in standard units (SI) has the value:

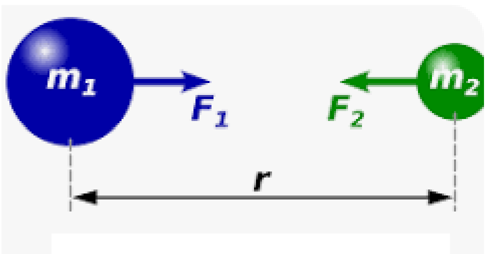
$$k_e = 8.9876 \times 10^9 \ N.m^2/C^2$$

The constant (k_e) can also be written as:

Whereas the constant ϵ_o (pronounced epsilon) is known as the "Permittivity Constant" of a vacuumhas the value:

Newton's law of universal gravitation

It states that: any two objects in the universe have an gravitational force between them that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

Where *G* is the universal gravitational constant

$$G = 6.67 \times 10^{-11} (N.m^2)/Kg^2$$