Conductors and Insulators

How many of you have experienced a feeling of electric shock while opening the window of your car or coming in contact with wires in wet condition? Isn't that a bit scary? But, why is that? Why don't you get similar experiences with wooden materials? It is because they are insulators.

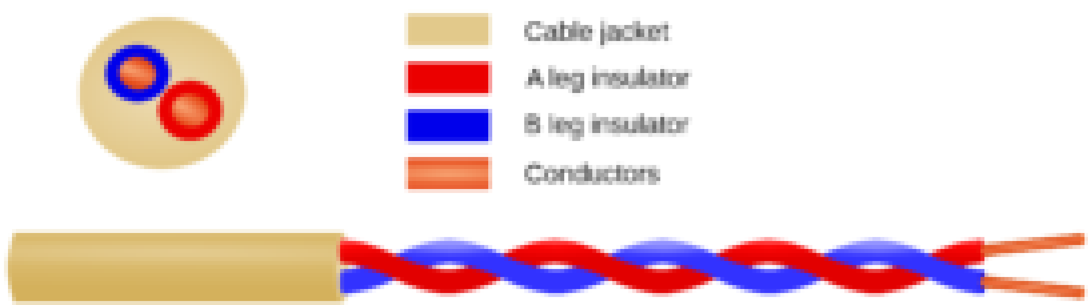
The reason you get a shock is that there occurs a flow of electrons from one body to another when they come in contact via rubbing or moving against each other. Shock is basically a mini feeling of current passing through your body. So now, let us look at these concepts in greater detail.

What are Conductors?

Conductors are the materials or substances which allow electricity to flow through them. They are able to conduct electricity because they allow electrons to flow inside them very easily. Conductors have this property of allowing the transition of heat or light from one source to another.

Metals, humans, earth, and animal bodies are all conductors. This is the reason we get electric shocks! The main reason is that being a good conductor, our human body allows a resistance-free path for the current to flow from wire to our body.

Conductors have free electrons on its surface which allows current to pass through. This is the reason why conductors are able to conduct electricity.



Examples of Conductors

- Silver is the best conductor of electricity. However, it is costly and so, we don't use silver in industries and transmission of electricity.

- Copper, Brass, Steel, Gold, and Aluminium are good conductors of electricity. We use them mostly in electric circuits and systems in the form of wires.
- Mercury is an excellent liquid conductor that finds use in many instruments.
- Gases are not good conductors of electricity as the particles of matter are quite far away and thus, they are unable to conduct electrons.

Explore more about Electric Charges and Fields

Electric Charges and Fields

- Dipole in a Uniform External Field
- Electric Dipole
- Applications of Gauss's Law
- Gauss's Law
- Electric Flux
- Electric Field Lines
- Electric Field
- Coulomb's Law
- Basic Properties of Electric Charge

- Electric Charge

Applications of Conductors

Conductors are quite useful in many ways. They find used in many real-life applications like:

- Mercury is a common ingredient in thermometer to check the temperature of the body.
- Aluminium finds use in making foils to store food and also in the production of fry pans to store heat quickly.
- Iron is common in vehicle engine manufacturing to conduct heat.
- The plate of an iron is made up of steel to absorb heat briskly.
- Conductors find their use in car radiators to eradicate heat away from the engine.

Insulators

Insulators are the materials or substances which resist or don't allow the current to flow through them. They are mostly solid in nature and are finding use in a variety of systems. They do not allow the flow of heat as well. The property which makes insulators different from conductors is its resistivity.

Wood, cloth, glass, mica, and quartz are some good examples of insulators. Insulators are also protectors as they give protection against heat, sound and of course passage of electricity. Insulators don't have any free electrons and it is the main reason why they don't conduct electricity.

Examples of Insulators

- Glass is the best insulator as it has the highest resistivity.
- Plastic is a good insulator and it finds its use in making a number of things.
- Rubber is a common component in making tyres, fire-resistant clothes and slippers. This is because it is a very good insulator.

Applications of Insulators

Being resistive to flow of electron, insulators find application worldwide in a number of ways. Some of the common uses include:

- Thermal Insulators, disallow heat to move from one place to another. We use them in making thermoplastic bottles, in fireproofing ceilings and walls.
- Sound Insulators help in controlling noise level, as they are good in absorbance of sound. Therefore, we use them in buildings, conference halls, and buildings to make them noise-free
- Electrical Insulators hinder the flow of electron or passage of current through them. We use them extensively in circuit boards, high-voltage systems and also in coating electric wire and cables.

Difference between Conductors and Insulators

Let us look at the basic difference between conductors and insulators in a nutshell.

Conductors	Insulators
A conductor allows current to flow through it.	Insulators don't allow current to flow through it.

Electric charge exists on the surface of conductors	Electric charges are absent in insulator.
Conductor don't store energy when kept in a magnetic field	Insulators store energy when kept in a magnetic field
Thermal conductivity (heat allowance) of a conductor is very high	Thermal conductivity of an insulator is very low
The resistance of a conductor is very low	The resistance of insulator is very high
Copper, Aluminium, and Mercury are some conductors	Wood, paper and ceramic are some insulators
Conductors are used in making electrical equipment.	Insulators are used in insulating electrical equipment for safety purpose

Solved Example for You

Question: How can you increase the conductivity of water?

Solution: Water is a good conductor of electricity. However, if you want to increase its conductivity, you can add some salt to it.

Electric Charge

Have you ever given a thought as to why you get a shock while coming in contact with a doorknob? Such instances need to be decoded as it will help you learn about the concept of electric charge. If you analyze a battery, there are two symbols, '+' and '-'. This is because these two ends are responsible for the transmission of positive & negative charges. Let us try to understand what is charge in a precise manner.

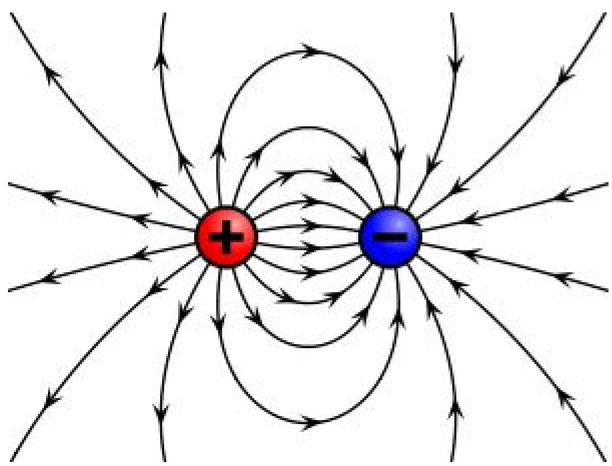
What is Charge?

It was Benjamin Franklin, famous American inventor who was responsible for assigning positive and negative standards of charge. In 1742, he started studying electricity which led to such conclusions. Before Franklin's analysis, most people assumed that electrical effects occurred due to the merger of two diverse electrical fluids (one negative and one positive).

After years of research and deductions, the concept of electric charge has been solidified and is actively taught to the global population. It should be known that the unit for calculating electric charge is coulomb (C); named after 18th-century French physicist, Charles-Augustin Coulomb.

He was the one who established the law which said: “like charges repel; unlike charges attract.” You can define a coulomb as the quantity of charge transferred by one ampere current for a duration of one second. Let’s further understand what is charge.

Introduction to Protons & Electrons



Majority of the electric charge is contained with the protons and electrons present within the atom. The negative charge is carried by electrons, whereas protons carry the positive charge. It is vital to know that, electrons and protons attract each other; the standard notion of “opposites attract” as framed by Coulomb.

Furthermore, protons and electrons are responsible for the development of electric fields, which apply a force termed as Coulomb force. This force is known to be outward radiating in all directions. Since protons are usually limited to the nuclei implanted inside atoms, their movement isn't that free as compared to electrons.

Hence, whenever there is a question related to electric charge, it always points out to surplus or shortage of electrons. In case some imbalance happens, and electrons are allowed to flow, the generation of electric current can be experienced. After understanding the data mentioned above, this is the point when the question: what is charge? grows a bit clear to the readers.

Solved Examples for You

Question: using a nuclear reaction, what happens to electric charge?

Answer: In the event of a nuclear reaction, the electric charge gets conserved considering an isolated system. This is true for any nuclear or chemical reaction, where the net electric charge stays constant. To be precise, the algebraic quantity of the essential charges stays the same.

Question: Explain the statement: ‘For a body, an electric charge is quantized’.

Answer: Considering a particular body, ‘electric charge is quantized’ refers to the fundamental number of electrons which can be transferred from that body to another. It should be noted that charges don’t get transported infractions. Therefore, the overall charge controlled by a body is simply the fundamental multiples of electric charge.

Basic Properties of Electric Charge

Do you remember how you used to play with magnets as kids? You must remember how equal poles used to repel each other. Don't you? Electric charges also behave similarly. However, we will start with the knowledge of the electric charge definition. Can you tell us what electric charge exactly is? Well, we will cover that in this chapter and we will also look at the various properties of electric charges.

Electric Charge Definition

Electric Charge is nothing but the amount of energy or electrons that pass from one body to another by different modes like conduction, induction or other specific methods. This is a basic electric charge definition. There are two types of electric charges. They are positive charges and negative charges.

Charges are present in almost every type of body. All those bodies having no charges are the neutrally charged ones. We denote a charge y the symbol 'q' and its standard unit is Coulomb. Mathematically, we can say that a charge is the number of electrons multiplied by the charge on 1 electron. Symbolically, it is

$Q = ne$

where q is a charge, n is a number of electrons and e is a charge on 1 electron (1.6×10^{-19}C). The two very basic natures of electric charges are

- Like charges repel each other.
- Unlike charges attract each other.

This means that while protons repel protons, they attract electrons. The nature of charges is responsible for the forces acting on them and coordinating the direction of the flow of them. The charge on electron and proton is the same in magnitude which is 1.6×10^{-19} C. The difference is only the sign that we use to denote them, + and -.

Basic Properties of Electric Charge

There are certain other basic properties that an electric charge follows from the electric charge definition. They are

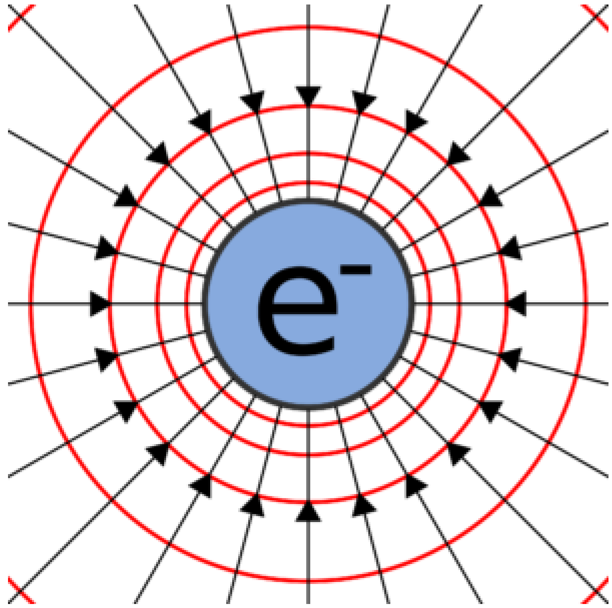
- Charges are additive in nature
- A charge is a conserved quantity
- Quantization of charge

Let us now look at these properties in greater detail.

Charges are Additive in Nature

This means that they behave like scalars and we can add them directly. As an example, let us consider a system which consists of two charges namely q_1 and q_2. The total charge of the system will be the algebraic sum of q_1 and q_2 i.e.$q_1 + q_2$. The same thing holds for a number of charges in a system. Let's say a system contains q_1, q_2, q_3, q_4 ………. q_n, then the net charge of the entire system will be

$= q_1 + q_2 + q_3 + q_4 + \ldots\ldots + q_n$



Charge is a Conserved Quantity

This implies that charge can neither be created nor be destroyed but can be transferred from one body to another by certain methods like conduction and induction. Does this remind you of the law of conservation of mass? As charging involves rubbing two bodies, it is actually a transfer of electrons from one body to another.

For example, if 5 C is the total charge of the system, then we can redistribute it as 1C, 2C, and 2C or in any other possible permutation. For example, sometimes a neutrino decays to give one electron and one proton by default in nature. The net charge of the system will be zero as electrons and protons are of the same magnitude and opposite signs.

Quantization of Charge

This signifies the fact that charge is a quantized quantity and we can express it as integral multiples of the basic unit of charge (e – charge on one electron). Suppose charge on a body is q, then we can write it as

$$q = ne$$

where n is an integer and not fraction or irrational number, like 'n' can be any positive or negative integer like 1, 2, 3, -5, etc. The basic unit of charge is the charge that an electron or proton carries. By convention, we take charge of the electron as negative and denote it as "-e" and charge on a proton is simply "e".

English experimentalist Faraday was the first to propose the quantization of charge principle. He did this when he put forward his experimental laws of electrolysis. Millikan in 1912, finally demonstrated and proved this principle.

1 A Coulomb of charge contains around 6×10^{18} electrons. Particles don't have a high magnitude of charge and we use micro coulombs or milli coulombs in order to express charge of a particle.

- $1 \mu C = 10^{-6}$ C
- $1 mC = 10^{-3}$ C

We can use the principle of quantization to calculate the total amount of charge present in a body and also to calculate a number of electrons or protons in a body. Suppose a system has n_1 number of electrons and n_2 number of protons, then the total amount of charge will be $n_2e - n_1e$.

Solved Example For You

Question: The charges of a system are +3 C, + 2 C, + 5 C and -4 C respectively. What would be the net charge of the system?

Solution: We know that the net charge of a system is the algebraic sum of individual charges. Let the total charge of the system be "Q". Then,

$Q = 3\ C + 2\ C + 5C – 4C$

$= 6\ C$

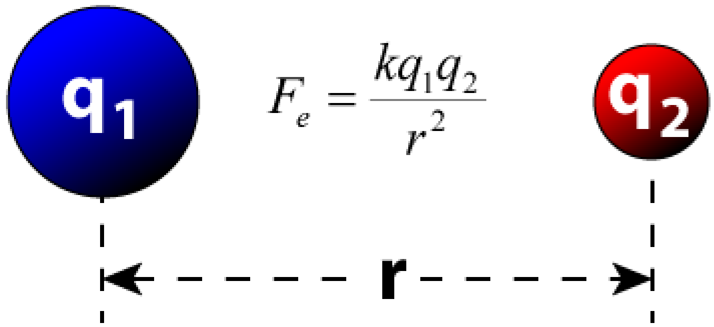
Coulomb's Law

Did you know that the world exists mainly because of the force of attraction and repulsion? It is mainly because of these attractions and repulsions between particles that the environment remains in a well-equipped and well-balanced form. One such practical application of this theory is the Coulomb's Law.

Do you know what Coulomb's Law is all about? Well, in order to find out the extent of repulsion or attraction force between two particles, having some charge, Charles – Augustin de Coulomb came up with the Coulomb's Law. We will learn about it in this chapter.

Coulomb's Law

Coulomb's Law gives an idea about the force between two point charges. By the word point charge, we mean that in physics, the size of linear charged bodies is very small as against the distance between them. Therefore, we consider them as point charges as it becomes easy for us to calculate the force of attraction/ repulsion between them.



Charles-Augustin de Coulomb, a French physicist in 1784, measured the force between two point charges and he came up with the theory that the force is inversely proportional to the square of the distance between the charges. He also found that this force is directly proportional to the product of charges (magnitudes only).

We can show it with the following explanation. Let's say that there are two charges q_1 and q_2. The distance between the charges is 'r', and the force of attraction/repulsion between them is 'F'. Then

$F \propto q_1q_2$

Or, $F \propto 1/r^2$

$F = k\, q_1q_2/ r^2$

where k is proportionality constant and equals to 1/4 π ε_0. Here, ε_0 is the epsilon naught and it signifies permittivity of a vacuum. The value of k comes 9×10^9 Nm^2/C^2 when we take the S.I unit of value of ε_0 is 8.854×10^{-12} $C^2 N^{-1} m^{-2}$.

According to this theory, like charges repel each other and unlike charges attract each other. This means charges of same sign will push each other with repulsive forces while charges with opposite signs will pull each other with attractive force.

Learn more about Gauss's Law here in detail

Vector Form of Coulomb's Law

The physical quantities are of two types namely scalars (with the only magnitude) and vectors (those quantities with magnitude and direction). Force is a vector quantity as it has both magnitude and direction. The Coulomb's law can be re-written in the form of vectors. Remember we denote the vector "F" as F, vector r as r and so on.

Let there be two charges q_1 and q_2, with position vectors r_1 and r_2 respectively. Now, since both the charges are of the same sign, there will be a repulsive force between them. Let the force on the q_1 charge due to q_2 be F_{12} and force on q_2 charge due to q_1 charge be F_{21}. The corresponding vector from q_1 to q_2 is r_{21} vector.

$r_{21} = r_2 – r_1$

To denote the direction of a vector from position vector r_1 to r_2, and from r_2 to r_1 as:

$$\hat{r}_{21} = \frac{r_{21}}{r_{21}}\ .\hat{r}_{12} = \frac{r_{12}}{r_{12}}\ .\hat{r}_{21} = \hat{r}_{12}$$

Now, the force on charge q_2 due to q_1, in vector form is:

$$F_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1\,q_2}{r_{21}^2}\,\hat{r}_{21}$$

The above equation is the vector form of Coulomb’s Law.

Remarks on Vector Form of Coulomb’s Law

While applying Coulomb’s Law to find out the force between two point charges, we have to be careful of the following remarks. The vector form of the equation is independent of signs of both the charges, as both the forces are opposite in nature.

The repulsive force F_{12} , that is the force on charge q_1 due to q_2 and another repulsive force F_{21} that is the force on charge q_2 due to q_1 are opposite in signs, due to change in position vector.

$F_{12} = -F_{21}$

This is because the position vector in case of force F_{12} is r_{12} and position vector in case of force F_{21} is r_{21}, now

$r_{21} = r_2 - r_1$

$r_{12} = r_1 - r_2$

Since both r_{21} and r_{12} are opposite in signs, they make forces of opposite signs too. This proves that Coulomb's Law fits into Newton's Third Law i.e. every action has its equal and opposite reaction. Coulomb's Law provides the force between two charges when they're present in a vacuum. This is because charges are free in a vacuum and don't get interference from other matter or particles.

Limitations of Coulomb's Law

Coulomb's Law is derived under certain assumptions and can't be used freely like other general formulas. The law is limited to following points:

- We can use the formula if the charges are static (in rest position)
- The formula is easy to use while dealing with charges of regular and smooth shape, and it becomes too complex to deal with charges having irregular shapes
- The formula is only valid when the solvent molecules between the particle are sufficiently larger than both the charges

Solved Example for You

Question: Two charges 1 C and – 3 C are kept at a distance of 3 m. Find the force of attraction between them.

Solution: We have q_1 = 1C, q_2 = – 3C and r = 3m. Then using Coulomb's Law and substituting above values we get

$F = k\ q_1q_2/\ r^2$

Or, $F = 9 \times 10^9 \times 1 \times 3/\ 3^2$

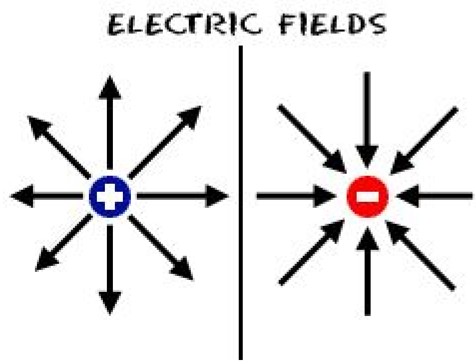
$F = 3 \times 10^9$ Newton

Electric Field

Electric Field: What do you think happens when you feel a shock when you touch an iron handle of a door or maybe another person? Obviously, due to an electric charge. These are charges that are accumulated on the surface after being rubbed against an insulator. That collected charge is able to find a conductor in touch to relieve itself hence causing an electric flow.

But there is also a finding by early scientists that even kept at a distance, two items are always exerting a certain amount of force on each other. Even if one of the charges has its position vacated and then return back to the position, the effect still remains in the area around the two. That charged area has been termed as Electric Field about which we will be exploring in depth.

Electric Field



Assume there are point charges (sizes <<< r) P and Q placed r distance apart in a vacuum. Both charges create an electric field around them which ultimately is responsible for the force applied by the two on each other. The Electric Field around Q at position r is:

E = kQ / r2

Where r is a unit vector of the distance r with respect to the origin. This value E(r) [SI unit N/C] amounts to an electric field of each charge based on its position vector r. When another charge q is brought at a certain distance r to the charge Q, a force is exerted by Q equal to:

F_Q = kQq/ r2

Now, there is an equal and opposite force exerted on Q by q which is equal to:

$F_q = kqQ/r^2$

Hence, if q is a unit charge, the force applied is equal to field value.

Electric Field due to a System of Charges

If there is a system of charges $q_1, q_2, \ldots q_n$ in space with position vectors $r_1, r_2, \ldots r_n$ and the net effect of the Electric Charges are required to be calculated on a unit test charge q with position vector r placed inside the system, then it is attributed to a superimposition of Electric field values for all charges by Coulomb's Law:

$E = E_1 + E_2 + \ldots + E_n$

$= kq_1/r_1^2 + kq_2/r_2^2 + \ldots + kq_n/r_n^2$

where $E_n(r_n)$ is the Electric Field value of charge n in the system with respect to position vector r_n. Here, E is a vector quantity and its value are attributed to change in the position of source charges.

Solved Examples for You

Question: Since the actual measurable quantity inside a system is an Electric Force, why has the intermediate notion of Electric Field been introduced at all? Explain its significance.

Solution: The study of electrostatics involves the use of the term electric field which may be convenient to explain the concepts but it is not really necessary. To explain the phenomenon of an electrical environment consisting of a system of charges, we use the term Electric Field.

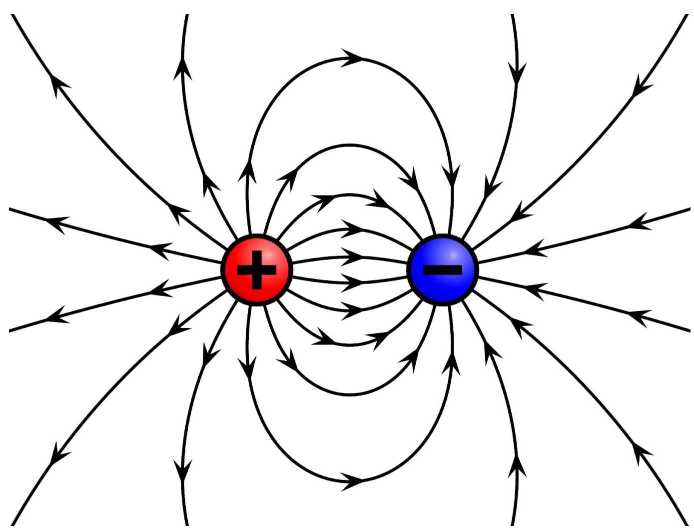
It is very useful in determining the amount of electric force applied to a unit test charge inside the system. But it also ensures that no change in the characteristics of charges happens due to the test charge. The term field is a strong interpretation of a value or quantity in space wrt the change in position at every point.

Hence, the field is a vector entity. And force is a vector value corresponding to it. There is another important scenario where electric field terminology plays an important role; that is, time-phenomena. Here, if a charge in motion applies force on another charge causing it too to be in motion, then the small time-delay in between can be attributed only to the notion of electric field. The natural notion is very useful in such a scenario in physics.

Electric Field Lines

Did you know that there are many interesting patterns that can be formed with the study of Electrical Field Lines? Well, you surely did not learn this in your geometry class, which is why you need to study the concept of Electric Field Lines to completely understand what it is all about. Let us take a look at the concept.

Electric Field Lines



An electric field can be used in the pictorial form to describe the overall intensity of the field around it. This pictorial representation is called the electric field lines. There are certain properties, rules, and applications of electric field lines. Electric Field Lines can be easily defined as a curve which shows the direction of an electric field when we draw a tangent at its point.

The concept of electric field was first proposed by Michael Faraday, in the 19th century. Faraday always thought of electric field lines as ones which can be used to describe and interpret the invisible electric field. Instead of using complex vector diagram each time, electric field lines can be used to describe the electric field around a system of charges in an easier way.

The strength of electric fields is usually directly proportional to the lengths of electric field lines. Also, since the electric field is inversely proportional to the square of the distance, the electric field strength decreases, as we move away from the charge. The direction of arrows of field lines depicts the direction of the electric field, which is pointing outwards in case of positive charge and pointing inwards in case of a negative charge.

Further, the magnitude of an electric field is well described by the density of charges. The lines closer to the charge represent a strong electric field and the lines away from charge correspond to the weak electric field. This is because the strength of the electric field decreases as we move away from the charge.

Properties of Electric Field Lines

Electric field lines generally show the properties to account for nature of electric fields. Some general properties of these lines are as follows:

- Electric field lines start from a positive charge and end at a negative charge, in case of a single charge, electric field lines end at infinity
- In a charge-free region, electric field lines are continuous and smooth
- Two electric field lines never intersect or cross each other, as if they do, there will be two vectors depicting two directions of the same electric field, which is not possible
- These lines never form a closed loop. This is because an electric field is conservative in nature and hence the lines don't form a closed loop

Solved Examples for You

Question: Calculate at what distance from a negative charge of 5.536 nC would the

electric field strength be equal to 1.90×10^5 N/C?

Solution: d = ?

q = 5.536 nC

$E = 1.90 \times 10^5$ N/C

$K = 9.0 \times 10^9$ N . m^2/C^2

The symbols nC stand for nano Coulombs. It is using the metric prefix "n". We know that

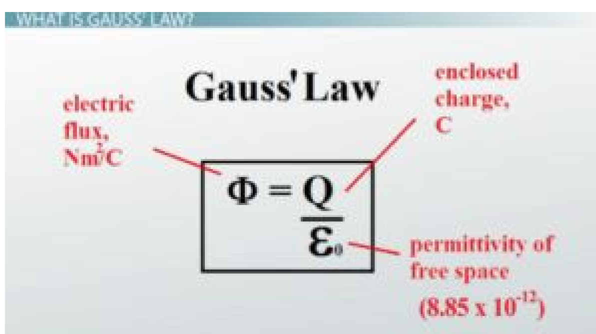
$E = Kq / d^2$

Substituting the values in the given formula we get, d = 1.6 cm. Hence the electric field strength will be equal to 1.90×10^5 N/C at a distance of 1.6 cm

Gauss's Law

The study of science is incredibly interesting and filled with fun facts. The deeper one dives into the concepts of science and its related fields, the greater amount of knowledge and information there is to learn in there. One such topic of study is the Gauss Law, which studies electric charge along with a surface and the topic of electric flux. Let us get to know more about the law and the manner of its operation so that we can understand the equation of the law.

Gauss's law



(Source: Study)

Gauss's law states that the net flux of an electric field in a closed surface is directly proportional to the enclosed electric charge. It is one of the four equations of Maxwell's laws of electromagnetism. It was initially formulated by Carl Friedrich Gauss in the year 1835 and relates the electric fields at the points on a closed surface and the net charge enclosed by that surface.

The electric flux is defined as the electric field passing through a given area multiplied by the area of the surface in a plane perpendicular to the field. Yet another statement of Gauss's law states that the net flux of a given electric field through a given surface, divided by the enclosed charge should be equal to a constant.

Usually, a positive electric charge is supposed to generate a positive electric field. The law was released in 1867 as part of a collection of work by the famous German mathematician, Carl Friedrich Gauss.

Gauss Law Equation

Let us now study Gauss's law through an integral equation. Gauss's law in integral form is given below:

$\int E \cdot dA = Q/\varepsilon_0$ ….. (1)

Where,

- E is the electric field vector

- Q is the enclosed electric charge
- ε_0 is the electric permittivity of free space
- A is the outward pointing normal area vector

Flux is a measure of the strength of a field passing through a surface. Electric flux is defined as

$\Phi = \int E \cdot dA$ …. (2)

We can understand the electric field as flux density. Gauss's law implies that the net electric flux through any given closed surface is zero unless the volume bounded by that surface contains a net charge.

Gauss's law for electric fields is most easily understood by neglecting electric displacement (d). In matters, the dielectric permittivity may not be equal to the permittivity of free-space (i.e. $\varepsilon \neq \varepsilon_0$). In the matter, the density of electric charges can be separated into a "free" charge density (ρ_f) and a "bounded" charge density (ρ_b), such that:

$P = \rho_f + \rho_b$

Solved Examples for You

Question: There are three charges q1, q2, and q3 having charge 6 C, 5 C and 3 C enclosed in a surface. Find the total flux enclosed by the surface.

Answer: Total charge Q,

$Q = q1 + q2 + q3$

$= 6\ C + 5\ C + 3\ C$

$= 14\ C$

The total flux, $\phi = Q/\epsilon_0$

$\phi = 14C / (8.854\times10^{-12}\ F/m)$

$\phi = 1.584\ Nm^2/C$

Therefore, the total flux enclosed by the surface is $1.584\ Nm^2/C$.

Applications of Gauss's Law

Now that you have a brief idea of what Gauss law is, let us look at the application of Gauss Law. Does that already look difficult to you? Well, no! We will make it easier for you! It is important to note that we can use Gauss's Law to solve complex electrostatic problems involving unique symmetries like cylindrical, spherical or planar symmetry. So, contrary to what you thought, the application of Gauss Law can actually make your task easier!

Application of Gauss Law

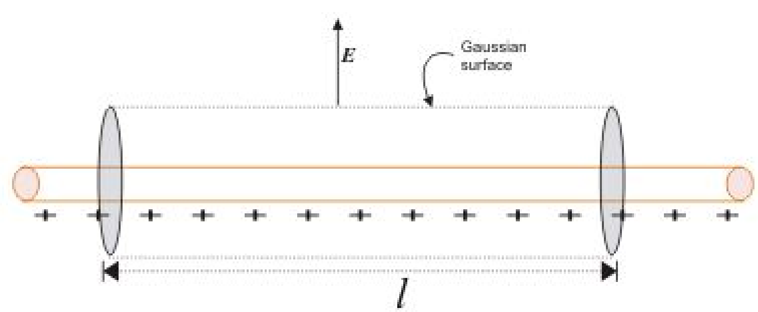
There are various applications of Gauss law which we will look at now. Just to start with, we know that there are some cases in which calculation of electric field is quite complex and involves tough integration. We use the Gauss's Law to simplify evaluation of electric field in an easy way.

Before we learn more about the applications, let us first see how we can apply the law. We must choose a Gaussian surface, such that the evaluation of the electric field becomes easy. One should make use of symmetry to make problems easier. We must also remember that it is not necessary for the Gaussian surface to coincide with the real surface. It can be inside or outside the Gaussian surface.

Electric Field due to Infinite Wire

Let us consider an infinitely long wire with linear charge density λ and length L. To calculate electric field, we assume a cylindrical Gaussian surface. As the electric field E is radial in direction, the flux through the end of the cylindrical surface will be zero.

This is because the electric field and area vector are perpendicular to each other. As the electric field is perpendicular to every point of the curved surface, we can say that its magnitude will be constant.



The surface area of the curved cylindrical surface is 2πrl. The electric flux through the curve is

$E \times 2\pi rl$

According to Gauss's Law

$$\Phi = \frac{q}{\varepsilon_0}$$

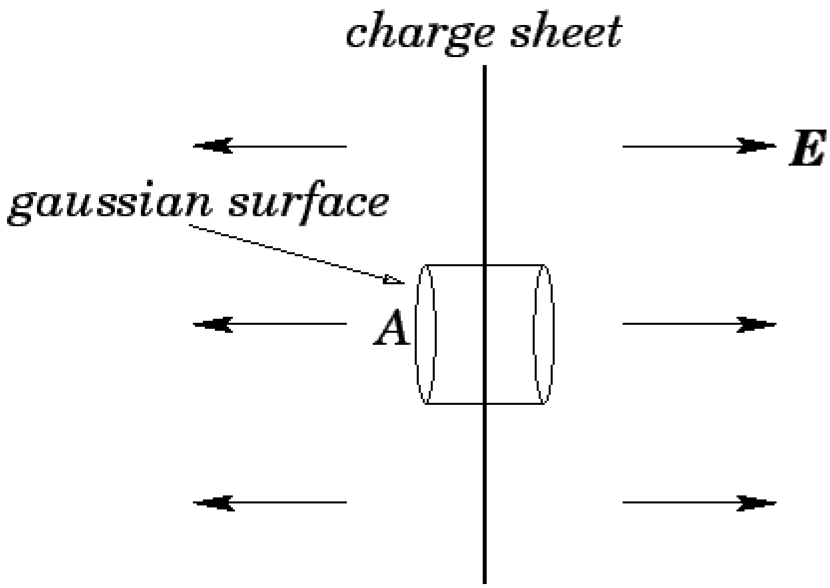
$$E \times 2\pi rl = \frac{\lambda l}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

You need to remember that the direction of the electric field is radially outward if linear charge density is positive. On the other hand, it will be radially inward if the linear charge density is negative.

Electric Field due to Infinite Plate Sheet

Let us consider an infinite plane sheet, with surface charge density σ and cross-sectional area A. The position of the infinite plane sheet is as below:



The direction of the electric field due to an infinite charge sheet is perpendicular to the plane of the sheet. Let us consider a cylindrical Gaussian surface, whose axis is normal to the plane of the sheet. We can evaluate the electric field E from Gauss's Law as according to the law:

$$\Phi = \frac{q}{\varepsilon_0}$$

Froma continuous charge distribution charge q will be the charge density (σ) times the area (A). Talking about net electric flux, we will consider electric flux only from the two ends of the assumed Gaussian surface. We can attribute it to the fact that the curved surface area and an electric field are normal to each other, thereby producing zero electric flux. So the net electric flux is

$\Phi = EA - (-EA)$

$\Phi = 2EA$

Then, we can write

$$2EA = \frac{\sigma A}{\varepsilon_0}$$

The term A cancels out which means electric field due to an infinite plane sheet is independent of cross-sectional area A and equals to:

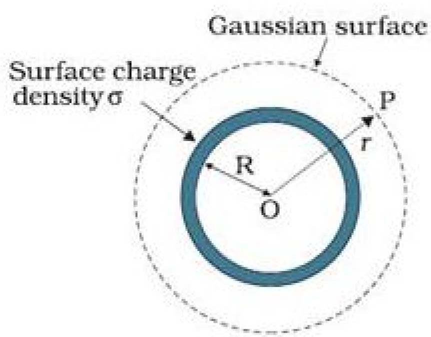
$$E = \frac{\sigma}{2\varepsilon_0}$$

Electric Field due to Thin Spherical Shell

Let us consider a thin spherical shell of surface charge density σ and radius "R". By observation, we can see that the shell has spherical symmetry. Therefore, we can evaluate the electric field due to the spherical shell in two different positions:

- Electric field outside the spherical shell
- Electric field inside the spherical shell

Let us look at these two cases in greater detail.



Electric Field Outside the Spherical Shell

To find electric field outside the spherical shell, we take a point P outside the shell at a distance r from the centre of the spherical shell. By symmetry, we take Gaussian spherical surface with radius r and centre O. The Gaussian surface will pass through P, and experience a constant electric field E all around as all points are equally distanced "r'' from the centre of the sphere. Then, according to Gauss's Law:

$$\Phi = \frac{q}{\varepsilon_0}$$

The enclosed charge inside the Gaussian surface q will be $\sigma \times 4\pi R^2$. The total electric flux through the Gaussian surface will be

$\Phi = E \times 4\pi r^2$

Then by Gauss's Law, we can write

$$E \times 4\pi r^2 = \sigma \times \frac{4\pi R^3}{\varepsilon_0}$$

$$E = \frac{\sigma R^2}{\varepsilon_0 \; r^2}$$

Putting the value of surface charge density σ as $q/4\pi R^2$, we can rewrite the electric field as

$$E = \frac{kq}{r^2}$$

In vector form, the electric field is

$$\vec{E} = \frac{kq}{r^2}\hat{r}$$

where r is the radius vector, depicting the direction of electric field. What we must note here is that if the surface charge density σ is negative, the direction of the electric field will be radially inward.

Electric Field Inside the Spherical Shell

To evaluate electric field inside the spherical shell, let's take a point P inside the spherical shell. By symmetry, we again take a spherical Gaussian surface passing through P, centered at O and with radius r. Now according to Gauss's Law

$$\Phi = \frac{q}{\varepsilon_0}$$

The net electric flux will be E × 4 π r2.

Solved Example for You

Question: Why is there no electric field inside a spherical shell?

Solution: The enclosed charge q will be zero, as we know that surface charge density is dispersed outside the surface, therefore there is no charge inside the spherical shell. Therefore, E = 0

This concludes our discussion on the topic of application of Gauss Law.

Electric Flux

When it comes to the study of science and the functioning of electricity, there is boundless knowledge and information that one stands to gain. The concept of Electric flux is one such field of study of science. It is pertinent to the understanding of electric force and its behavior. Let us study more about the concept of Electric flux.

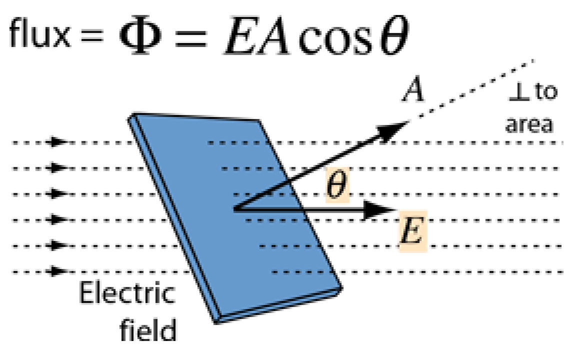
What is Electric Flux?

Electric flux is a property of an electric field. It may be thought of as the number of forces that intersect a given area. Electric field lines are usually considered to start on positive electric charges and to end on negative charges. Field lines directed into a closed surface are considered negative; those directed out of a closed surface are positive.

If there is no given net charge within a given closed surface then every field line directed into the given surface continues through the interior and is usually directed outward elsewhere on the surface. The negative flux just equals in magnitude the positive flux, so that the net or total, electric flux is zero.

If a net charge is contained inside a closed surface, the total flux through the surface is proportional to the enclosed charge, positive if it is positive, negative if it is negative.

Gauss's Law



The mathematical relation between electric flux and the enclosed charge is known as Gauss law for the electric field. It is one of the fundamental laws of electromagnetism. In the related meter-kilogram-second system and the International System of Units (SI) the net flux of an electric field through any closed surface is usually equal to the enclosed charge, in units of coulombs, divided by a constant, called the permittivity of free space.

In the centimeter-gram-second system, the net flux of an electric field through any closed surface is equal to the consistent 4π times the enclosed charge, measured in electrostatic units (esu). Electric flux is proportional to the number of electric field lines going through a virtual surface. You can understand this with an equation.

If the electric field is uniform, the electric flux (Φ_E) passing through a surface of vector area S is:

$\Phi_E = E \cdot S = ES\cos\theta$,

where E is the magnitude of the electric field (having units of V/m), S is the area of the surface, and θ is the angle between the electric field lines and the normal (perpendicular) to S. For a non-uniform electric field, usually the electric flux $d\Phi_E$ through a small surface area dS is denoted by:

$d\Phi_E = E \cdot dS$,

where the electric field is E, multiplied by the component of area perpendicular to the field.

Solved Examples for You

Question: An electric field of 500 V/m makes an angle of 30.00 with the surface vector. It has a magnitude of 0.500 m2. Find the electric flux that passes through the surface.

Solution: The electric flux which is passing through the surface is given by the equation as:

$\Phi_E = E.A = EA \cos \theta$

$\Phi_E = (500 \text{ V/m}) (0.500 \text{ m}^2) \cos 30$

$\Phi_E = 217 \text{ V m}$

Notice that the unit of electric flux is a volt-time a meter.

Question: Consider a uniform electric field $E = 3 \times 10^3 \hat{i}$ N/C. What is the flux of this field through a square of 10 cm on a side whose plane is parallel to the yz plane?

A. 30 Nm^2 / C

B. 40 Nm^2 / C

C. 50 Nm^2 / C

D. 60 Nm^2 / C

Solution: The flux of an electric field is given by,

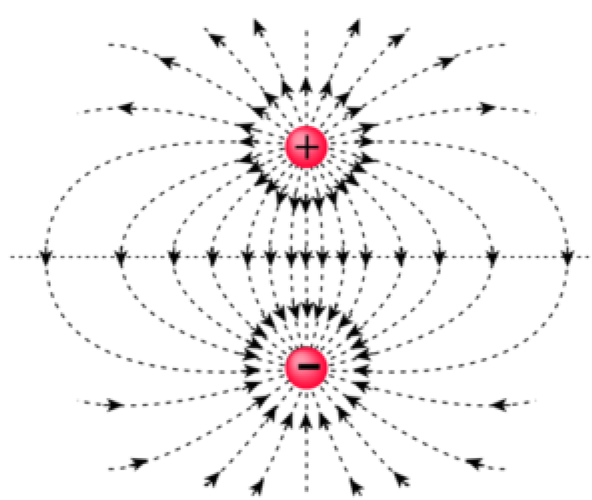
$\phi = EA \Rightarrow \phi = 3 \times 10^3 \times 0.1 \times 0.1 \Rightarrow \phi = 30\ Nm^2/C$

Therefore, the flux of the field through a square of 10 cm on a side whose plane is parallel to the yz plane is 30 Nm^2/C

Electric Dipole

Electric charge is present around us and there are many different examples to prove this phenomenon. Have you ever tried rubbing a comb-over a towel and brought it close to your hair? You will see that some of your hair tend to get attracted to the comb. This is basically due to the generation of Electric Charge. In this section, we will try to decode the behavior of opposite charges when kept at a distance. This is the concept of the Electric Dipole which is a vital portion of electrostatics.

Introduction to Electric Dipole



An electric dipole is tagged as a pair of objects which possess equal & opposite charges, parted by a significantly small distance. Let us take two charges having equal magnitude 'Q', which are separated by the distance 'D'.

Here we assume the first charge to be negative, while the second charge stays positive. You can call this particular combination as an electric dipole. Hence, we can state that an electric dipole is formed due to the grouping of equal & opposite charges when separated by an assured distance.

What is the Dipole Moment?

It is basically the exact measure of the strength associated with an electric dipole. Based on scientific and mathematical conclusions, the dipole moment magnitude is the product of either of the charges and the separation distance (d) between them. Do remember that, the dipole moment is a vector measure whose direction runs from negative to a positive charge.

The formula for electric dipole moment for a pair of equal & opposite charges is p = qd, the magnitude of the charges multiplied by the distance between the two.

Dipole Placed in Electric Field

Although the two forces acting on the dipole ends cancel each other as free vectors, they do act as different points. Hence, it does develop a torque on the dipole. Further, there is a rotating effect due to this torque which is experienced by the dipole.

The torque (t) magnitude considering the dipole center is the sum of the two forces times their respective distance arms, that is:

$|t| = 2q\ |E|a \sin q$

$= \ |p||E| \sin q$

$t = p \times E$ (expressed in newton-meter)

Therefore, in the presence of the uniform electric field, a dipole tends to align itself parallel to the concerned field. For this to happen, there are other conditions too, that is, orientation stays at some non-zero angle denoted as 'q'. Further, potential energy needs to be stored in the dipole at a preferred orientation, which starts from q = 0 to a nonzero q.

Solved Examples for You

Question: What is the dipole moment for a dipole having equal charges -2C and 2C separated with a distance of 2cm.

Solution: The calculated dipole moment for this condition is, p = q x d. Thus, p = 2 x 0.02 = 0.04 C-m.

Question: What is electric potential for a dipole? Electric potential due to a Dipole (V)

Solution: Let us assume there are two charges, –q, fixed at point A, and +q fixed at point B. These two are separated by a distance d, thus creating a dipole. Now, suppose the midpoint between AB is O. Therefore, the electric potential as a result of the dipole placed at any point P, when OP = r, is calculated as:

$V = (1/4\pi\varepsilon) \times p\cos\Theta / r^2$

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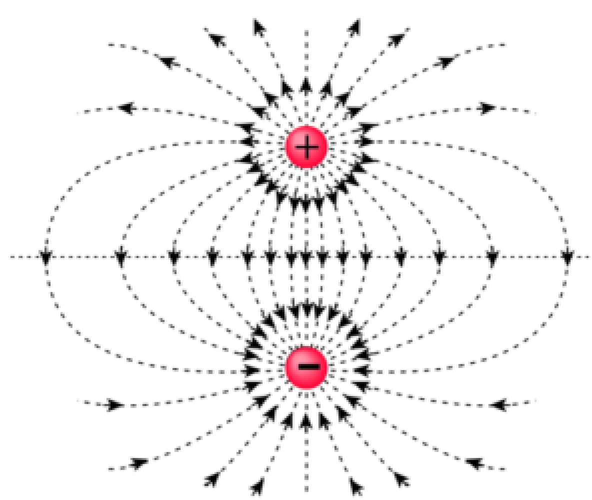

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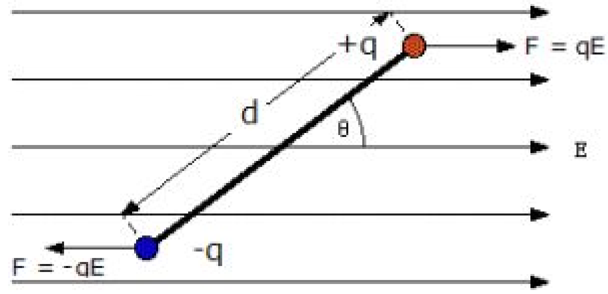
Dipole in a Uniform External Field

Dipole: Science is indeed mysterious and doesn't stop to surprise you as and when different topics are discussed. We are already familiar with the fact that charge exists around us and its presence leads to several natural phenomena. In addition, positive and negative charges are present in different forms that showcase diverse properties in the attendance of a motivating field.

Have you ever heard about the concept of an electric dipole? This unique setup of electric charges, i.e., positive & negative charges does form an interesting concept of physics. To be precise, an Electric Dipole can be tagged as a separation between positive and negative charges.

For example, you can consider a pair of electric charges having opposite sign but equal magnitude, parted by a significantly smaller distance. Our focus at present is to analyze the behavior of an Electric Dipole in the presence of an external field. This information is carefully decoded and presented in the following sections.

Dipole Placed in Uniform External Field



Since the impact of an external electric field on charges is already known to us; a dipole too will experience some form of force when introduced to an external field. It is interesting to learn that, a dipole placed in an external electric field acquires a rotating effect. This rotating effect is termed as 'torque' felt by the dipole. Excitingly, the net torque can be calculated on the opposite charges present in a dipole for estimating the overall rotation.

Torque & Its Calculation

In order to find torque experienced by a dipole when placed in an external field, let us consider that the dipole is introduced to a uniform external field. This field will generate an electric force having qE magnitude on the positive charge in the upward direction, whereas downward direction for the negative charge.

We can spot that the dipole rests in transitional equilibrium since the net force is zero. But what is the rotational equilibrium? Considering this case, the dipole might stay in a stationary position but does rotate with a particular angular velocity.

This fact has been proven experimentally and reveals that both electrostatic forces (qE) function as a torque being applied in the clockwise direction. Therefore, the dipole does get to rotate when placed in the uniform external electric field.

Always remember that torque always operates in a couple. Moreover, its magnitude is equivalent to the resultant product of force & its arm. Here, the arm can be seen as the distance falling between the point at which force operates and the point at which rotation occurs for the dipole.

Dipole Placed in the Uniform External Electric Field

For a dipole placed in the uniform external electric field, the origin is taken as the point. Furthermore, torque is represented by ‘τ’ symbol.

Do remember that, torque is a vector quantity. As per mathematical basis,

Torque magnitude (τ) = $q E \times 2a \sin\theta$

$\tau = 2 q a E \sin\theta$

$\tau = p E \sin\theta$ (Since $p = 2 q a$)

Therefore, we can say that the cross product of the electric field and dipole moment is the vector form of torque.

Solved Examples for You

Question: Give a real-life example of a dipole and electric field.

Solution: Try combing your dry hair and quickly bring the comb to several paper pieces. It would be observed that the comb pulls the paper pieces. This is because the comb acquires charge due to induction.

In a different way, the comb is known to polarize the paper pieces, i.e., produce a net dipole moment (direction of the electric field).

Further, since the electric field stays non-uniform, the pieces of paper get attracted in the direction of the comb.

Question: An electric dipole is placed at an angle of 30^o with an electric field of intensity 2×10^5 N/C. It experiences a torque of 4Nm. Calculate the charge on the dipole if the dipole length is 2cm.

A. 4

B. 2

C. 8

D. 1

Solution: B. Torque $\tau = p \times E = pE\sin\theta$

$4 = p \times 2 \times 105 \times \sin 30°$

Or, $p = 42 \times 105 \times \sin 30° = 4 \times 10^{-5}$ Cm

$q = p / l = 4 \times 1\,0^{-5} / 0.02 = 2 \times 10^{-3}$ C =2 mC