DEPARTMENT OF EDUCATION
SCHOOLS DIVISION OF NEGROS ORIENTAL
REGION VII
Kagawasan Ave., Daro, Dumaguete City, Negros Oriental

ELECTRIC CHARGE AND ELECTRIC FIELD

for GENERAL PHYSICS 2/ Grade 12/ Quarter 3/ Week 1

SELF-LEARNING KIT

NegOr_Q3_GenPhysics2_SLKWeek1_v2

FOREWORD

Electrical phenomena result from a fundamental property of matter: electric charge. The atoms that constitute most matter we encounter contain charged particles. Protons and electrons each have one unit charge, but of opposite sign. Atoms are generally neutral because the number of electrons and protons are the same.

Electric charges at rest have been known much longer than electric current. It was discovered centuries ago that certain types of materials would mysteriously attract one another after being rubbed together. For example, after rubbing a piece of silk against a piece of glass, the silk and glass would tend to stick together. Indeed, there was an attractive force that could be demonstrated even when the two materials were separated. In this SLK, we will learn more about role of electron transfer in electrostatic.

An electric field on the other hand, is an elegant way of characterizing the electrical environment of a system of charges. The electric field at any point in space around a system of charges represents the force a unit positive test charge would experience if placed at that point. The term field in physics generally refers to a quantity that is defined at every point in space and may vary from point to point. The electric field is a vector field since force is a vector quantity.

In this Self-Learning Kit, we will explore the knowledge of the value of the electric field at a point and which is all that is needed to determine what will happen to electric charges close to that particular point.

OBJECTIVES

At the end of this Self–Learning Kit, you should be able to:

K: explain the role of electron transfer in electrostatic charging by rubbing and charging by induction;
S: calculate the electric field due to a system of point charges using Coulomb's law and the superposition principle; and
A: recognize the real-world applications of the study of electrostatics.

LEARNING COMPETENCIES

Describe using a diagram charging by rubbing and charging by induction **(STEM_GP12EMIIIa-1).**

Explain the role of electron transfer in electrostatic charging by rubbing **(STEM_GP12EMIIIa-2).**

Describe experiments to show electrostatic charging by induction **(STEM_GP12EMIIIa-3).**

Calculate the net electric force on a point charge exerted by a system of point charges **(STEM_GP12EMIIIa-6).**

Describe an electric field as a region in which an electric charge experiences a force. **(STEM_GP12EM-IIIa-7)**

Calculate the electric field due to a system of point charges using Coulomb's law and the superposition principle. **(STEM_GP12EM-IIIa-10)**

Calculate the electric flux through a surface given the electric field. **(STEM-GP12EM-IIIb-12)**

Use Gauss' Law to infer the electric field due to uniformly distributed charges on long wires, spheres, and large plates. **(STEM-GP12-IIIb-13)**

Solve problems involving electric charges, dipoles, forces, fields, and flux in contexts such as, but not limited to, systems of point charges, classical models of the atom, electrical breakdown of air, charged pendulums, control of electron and proton beams, electrostatic ink-jet printers. **(STEM_GP12EMIIIb-14)**

I. WHAT HAPPENED

PRE-TEST

Directions: Read the sentences carefully then select the letter of the correct answer. Write the letter of your choice in your notebook/answer sheet.

1. The property of material due to which it attracts or repels other objects is ________________.
   a. friction b. velocity c. current d. charge
2. Plastic rod rubbed with fur and glass rod rubbed with silk will
   a. repel each other b. mix up with each other
   c. attract each other d. none of above
3. A negative change ___________.
   a. repels neutral charge b.attracts neutral charge
   c. repels negative charge d. repel positive charge
4. The electric charge between two bodies can be produced by _______.
   a. sticking b. rubbing c. oiling d. passing AC current
5. If mica and woolen cloth are rubbed together, then mica gets
   a. positively charged b. negatively charged
   c. remains neutral d. dual charged
6. The net accumulation of electric charges on an object.
   a. current b. Static electricity c. voltage d. negatively charged
7. An area surrounding an electron that exerts a force on anything nearby with an electric charge.
   a. green field b. flux c. electric field d. lumen
8. What is a large discharge of static electricity?
   a. lightning b. rain floods c. floods d. wind
9. What charges attract?
   a. like b. opposite c. negative d. positive
10. What charges repel?
    a. like b. opposite c. negative d. positive
11. A negatively charged particle is placed in a uniform electric field directed from South to North. In which direction will the particle move after it is released?
    a. West b. East c. South d. North
12. What is the SI unit for the electric field?
    a. Newtons c. Newtons per Coulomb
    b. Coulombs d. Newtons per meter
13. For a negative source charge, the lines will point _____________.
    a. inward b. outward c. sideward d. away
14. Field lines start from a ___________________.
    a. Negative charge c. proton
    b. positive charge d. neutron

15. Field lines ends on a ____________________.
    a. negative charge c. proton
    b. positive charge d. neutron
16. ____________________ states that the net flux of an electric field in a closed surface is directly proportional to the enclosed electric charge.
    a. Coulomb's Law c. Faraday's Law
    b. Gauss Law d. Ohm's Law
17. ____________________ 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.
    a. Electromagnetism c. Electric Flux
    b. Electric Charge d. Electric Field
18. If the flux is going from the inside to the outside, we call that a ____________flux.
    a. Positive c. Negative
    b. Neutral d. Cannot Tell
19. The field inside the uniformly distributed spherically symmetric charge distribution increases linearly with __________.
    a. r b. θ c. dA d. E_0
20. There are three charges q_1, q_2, and q_3 having charge 6C, 5C and 3C enclosed in a surface. Find the total flux enclosed by the surface.
    a. 2.584 Nm^2/C c. 1.584 Nm^2/C
    b. 3.584 Nm^2/C d. 4.584 Nm^2/C

II. WHAT I NEED TO KNOW

DISCUSSION

The ancient Greeks discovered as early as 600 B.C. that after they rubbed amber with wool, the amber could attract other objects. Today we say that the amber has acquired a net electric charge, or has become charged. The word "electric" is derived from the Greek word *elektron*, meaning *amber*. When you scuff your shoes across a nylon carpet, you become electrically charged, and you can charge a comb by passing it through dry hair. Plastic rods and fur (real or fake) are particularly good for demonstrating electrostatics, the interactions between electric charges that are at rest (or nearly so). After we charge both plastic rods.1a by rubbing them with the piece of fur, we find that the rods repel each other. When we rub glass rods with silk, the glass rods also become charged and repel each other (1b). But a charged plastic rod attracts a charged glass rod; furthermore, the plastic rod and the fur attract each other, and the glass rod and the silk attract each other (1c). These experiments and many others like them have shown that there are exactly two kinds of electric charge: the kind on the plastic rod rubbed with fur and the kind on the glass rod rubbed with silk. Benjamin Franklin (1706–1790) suggested calling these two kinds of charge negative and positive, respectively, and these names are still used. The plastic rod and the silk have negative charge; the glass rod and the fur have positive charge.

Two positive charges or two negative charges repel each other. A positive charge and a negative charge attract each other.

Electric Attraction and Repulsion

The attraction and repulsion of two charged objects are sometimes summarized as *"Like charges repel, and opposite charges attract."* But keep in mind that the phrase "like charges" does not mean that the two charges are exactly identical, only that both charges have the same algebraic sign (both positive or both negative). "Opposite charges" means that both objects have an electric charge, and those charges have different signs (one positive and the other negative).

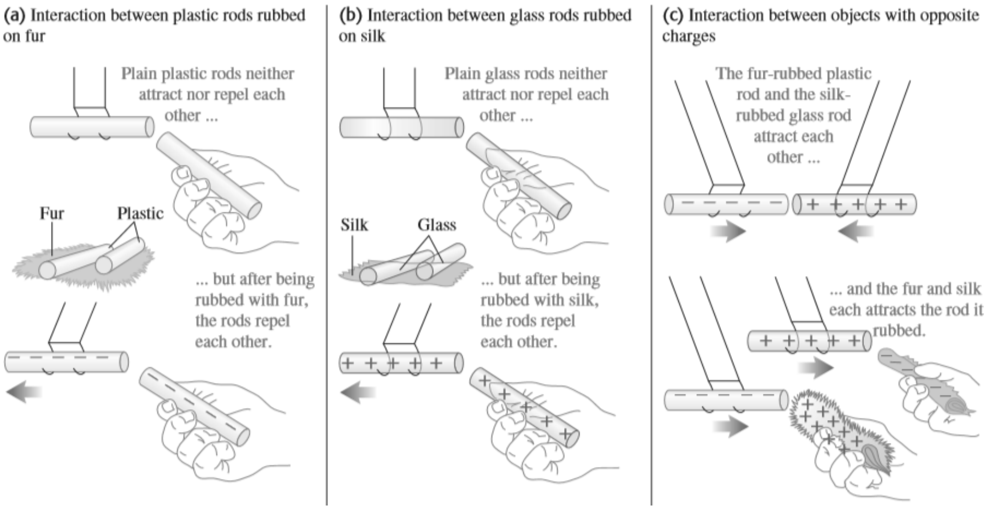


Figure 1. Experiments in electrostatics. (a) Negatively charged objects repel each other. (b) Positively charged objects repel each other. (c) Positively charged objects and negatively charged objects attract each other.

One application of forces between charged bodies is in a laser printer. The printer's light-sensitive imaging drum is given a positive charge. As the drum rotates, a laser beam shines on selected areas of the drum, leaving those areas with a negative charge. Positively charged particles of toner adhere only to the areas of the drum "written" by the laser. When a piece of paper is placed in contact with the drum, the toner particles stick to the paper and form an image.

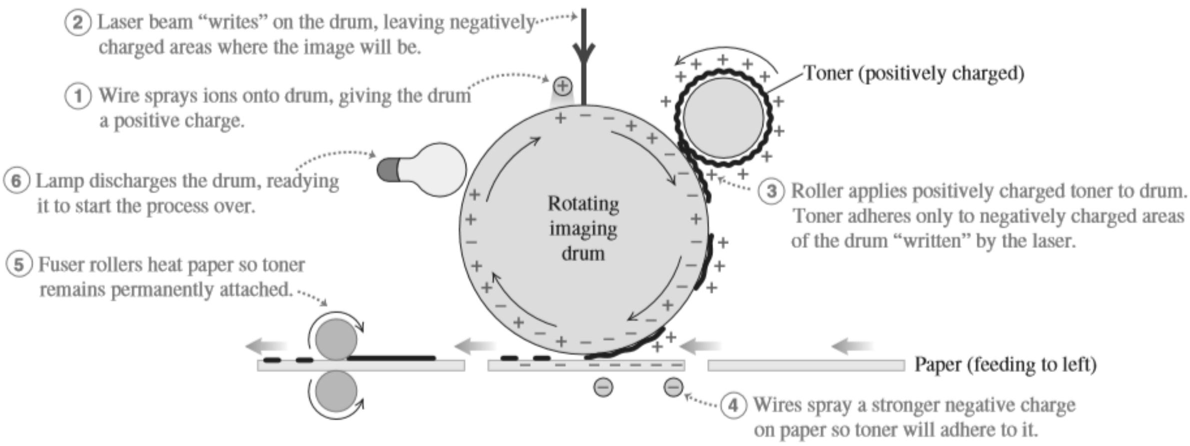


Figure 2. Schematic diagram of the operation of a laser printer

Conductors and Insulators

Figure 3. This power adapter uses metal wires and connectors to conduct electricity from the wall socket to a laptop computer. The conducting wires allow electrons to move freely through the cables, which are shielded by rubber and plastic. These materials act as insulators that don't allow electric charge to escape outward. *(credit: Evan-Amos, Wikimedia Commons)*

Some substances, such as metals and salty water, allow charges to move through them with relative ease. Some of the electrons in metals and similar conductors are not bound to individual atoms or sites in the material. These free electrons can move through the material much as air moves through loose sand. Any substance that has free electrons and allows charge to move relatively freely through it is called a **conductor.** The moving electrons may collide with fixed atoms and molecules, losing some energy, but they can move in a conductor. Superconductors allow the movement of charge without any loss of energy. Salty water and other similar conducting materials contain free ions that can move through them. An ion is an atom or molecule having a positive or negative (nonzero) total charge. In other words, the total number of electrons is not equal to the total number of protons.

Other substances, such as glass, do not allow charges to move through them. These are called **insulators.** Electrons and ions in insulators are bound in the structure and cannot move easily—as much as 10^{23} times more slowly than in conductors. Pure water and dry table salt are insulators, for example, whereas molten salt and salty water are conductors.

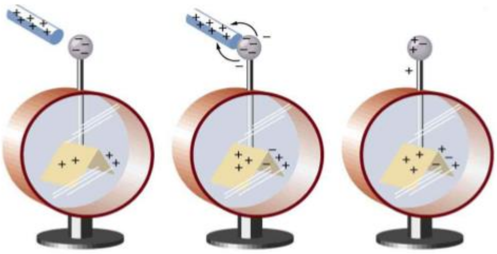


Figure 4. An electroscope is a favorite instrument in physics demonstrations and student laboratories. It is typically made with gold foil leaves hung from a (conducting) metal stem and is insulated from the room air in a glass-walled container. (a) A positively charged glass rod is brought near the tip of the electroscope, attracting electrons to the top and leaving a net positive charge on the leaves. Like charges in the light flexible gold leaves repel, separating them. (b) When the rod is touched against the ball, electrons are attracted and transferred, reducing the net charge on the glass rod but leaving the electroscope positively charged. (c) The excess charges are evenly distributed in the stem and leaves of the electroscope once the glass rod is removed.

Charging by Contact

Figure 4 above shows an electroscope being charged by touching it with a positively charged glass rod. Because the glass rod is an insulator, it must actually touch the electroscope to transfer charge to or from it. (Note that the extra positive charges reside on the surface of the glass rod as a result of rubbing it with silk before starting the experiment.) Since only electrons move in metals, we see that they are attracted to the top of the electroscope. There, some are transferred to the positive rod by touch, leaving the electroscope with a net positive charge.

Electrostatic repulsion in the leaves of the charged electroscope separates them. The electrostatic force has a horizontal component that results in the leaves moving apart as well as a vertical component that is balanced by the gravitational force. Similarly, the electroscope can be negatively charged by contact with a negatively charged object.

Charging by Induction

It is not necessary to transfer excess charge directly to an object in order to charge it. Figure 5 shows a method of ***induction*** wherein a charge is created in a nearby object, without direct contact. Here we see two neutral metal spheres in contact with one another but insulated from the rest of the world. A positively charged rod is brought near one of them, attracting negative charge to that side, leaving the other sphere positively charged.

This is an example of induced ***polarization*** of neutral objects. ***Polarization*** is the separation of charges in an object that remains neutral. If the spheres are now separated (before the rod is pulled away), each sphere will have a net charge. Note that the object closest to the charged rod receives an opposite charge when charged by induction. Note also that no charge is removed from the charged rod, so that this process can be repeated without depleting the supply of excess charge.

Another method of charging by induction is shown in Figure 6. The neutral metal sphere is polarized when a charged rod is brought near it. The sphere is then grounded, meaning that a conducting wire is run from the sphere to the ground. Since the earth is large and most ground is a good conductor, it can supply or accept excess charge easily. In this case, electrons are attracted to the sphere through a wire called the ground wire, because it supplies a conducting path to the ground. The ground connection is broken before the charged rod is removed, leaving the sphere with an excess charge opposite to that of the rod. Again, an opposite charge is achieved when charging by induction and the charged rod loses none of its excess charge.

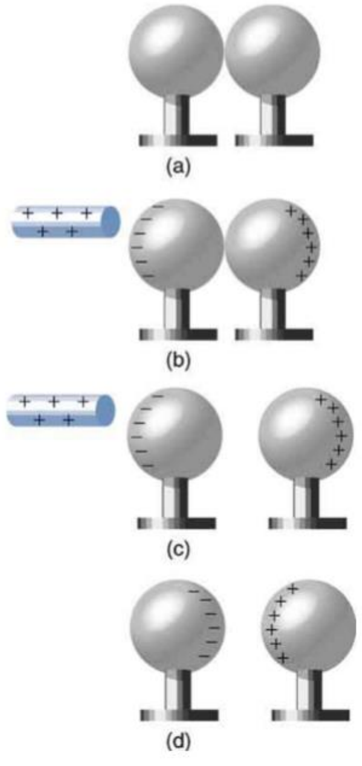


Figure 5. Charging by induction. (a) Two uncharged or neutral metal spheres are in contact with each other but insulated from the rest of the world. (b) A positively charged glass rod is brought near the sphere on the left, attracting negative charge and leaving the other sphere positively charged. (c) The spheres are separated before the rod is removed, thus separating negative and positive charge. (d) The spheres retain net charges after the inducing rod is removed—without ever having been touched by a charged object.

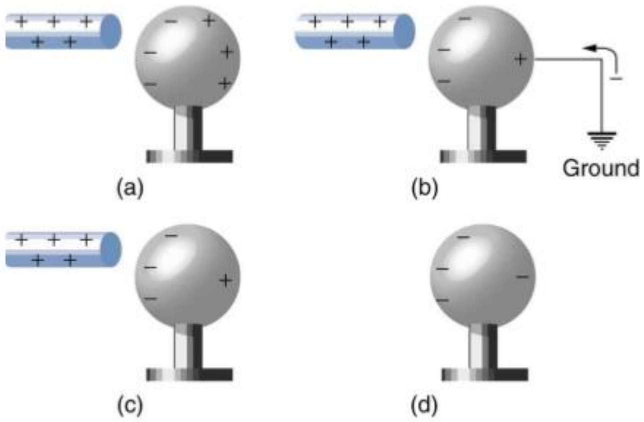


Figure 6. Charging by induction, using a ground connection. (a) A positively charged rod is brought near a neutral metal sphere, polarizing it. (b) The sphere is grounded, allowing electrons to be attracted from the earth's ample supply. (c) The ground connection is broken. (d) The positive rod is removed, leaving the sphere with an induced negative charge.

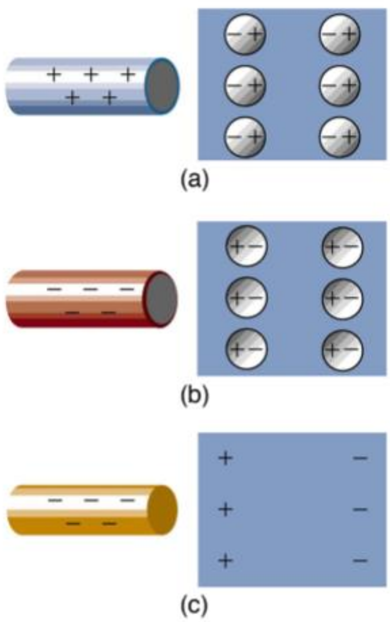


Figure 7. Both positive and negative objects attract a neutral object by polarizing its molecules. (a) A positive object brought near a neutral insulator polarizes its molecules. There is a slight shift in the distribution of the electrons orbiting the molecule, with unlike charges being brought nearer and like charges moved away. Since the electrostatic force decreases with distance, there is a net attraction. (b) A negative object produces the opposite polarization, but again attracts the neutral object. (c) The same effect occurs for a conductor; since the unlike charges are closer, there is a net attraction.

Neutral objects can be attracted to any charged object. The pieces of straw attracted to polished amber are neutral, for example. If you run a plastic comb through your hair, the charged comb can pick up neutral pieces of paper. Figure 7 shows how the polarization of atoms and molecules in neutral objects results in their attraction to a charged object.

When a charged rod is brought near a neutral substance, an insulator in this case, the distribution of charge in atoms and molecules is shifted slightly. Opposite charge is attracted nearer the external charged rod, while like charge is repelled. Since the electrostatic force decreases with distance, the repulsion of like charges is weaker than the attraction of unlike charges, and so there is a net attraction. Thus a positively charged glass rod attracts neutral pieces of paper, as will a negatively charged rubber rod. Some molecules, like water, are polar molecules. Polar molecules have a natural or inherent separation of charge, although they are neutral overall. Polar molecules are particularly affected by other charged objects and show greater polarization effects than molecules with naturally uniform charge distributions.

Coulomb's Law

Through the work of scientists in the late 18th century, the main features of the ***electrostatic force***—the existence of two types of charge, the observation that like charges repel, unlike charges attract, and the decrease of force with distance—were eventually refined, and expressed as a mathematical formula. The mathematical formula for the electrostatic force is called Coulomb's law after the French physicist Charles Coulomb (1736–1806), who performed experiments and first proposed a formula to calculate it.

Coulomb's Law

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

Coulomb's Law calculates the magnitude of the force F between two point charges, q_1 and q_2 , separated by a distance r. In SI units, the constant k is equal to

$$k = 8.988\,x\,10^9 \frac{N \cdot m^2}{C^2} \approx 8.99\,x 10^9 \frac{N \cdot m^2}{C^2}$$

The electrostatic force is a vector quantity and is expressed in units of newtons. The force is understood to be along the line joining the two charges. (See Figure 8)

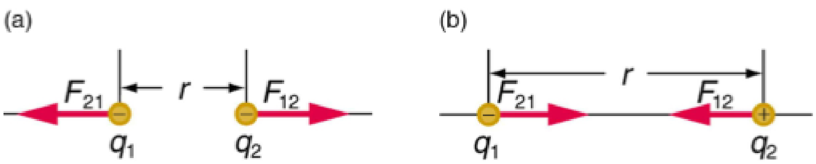


Figure 8. The magnitude of the electrostatic force F between point charges q_1 and q_2 separated by a distance r is given by Coulomb's law. Note that Newton's third law (every force exerted creates an equal and opposite force) applies as usual—the force on q_1 is equal in magnitude and opposite in direction to the force it exerts on q_2. (a) Like charges. (b) Unlike charges.

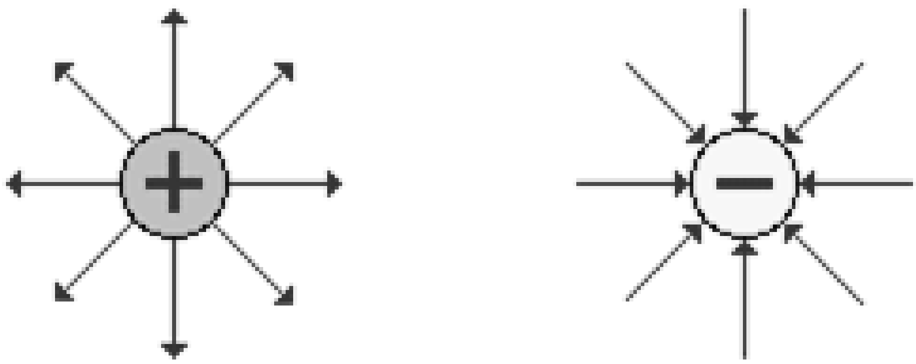
Electric Field

Electric force is described as a non-contact force. A charged balloon can have an attractive effect upon an oppositely charged balloon even when they are not in contact. The electric force acts over the distance separating the two objects. Electric force is an action-at-a-distance force.

Action-at-a-distance forces are sometimes referred to as field forces. The concept of a **field force** is utilized by scientists to explain this rather unusual force phenomenon that occurs in the absence of physical contact. The space surrounding a charged object is affected by the presence of the charge; an electric field is established in that space. A charged object creates an electric field - an alteration of the space or field in the region that surrounds it. Other charges in that field would feel the unusual alteration of the space. Whether a charged object enters that space or not, the electric field exists. Space is altered by the presence of a charged object; other objects in that space experience the strange and mysterious qualities of the space. As another charged object enters the space and moves *deeper and deeper* into the field, the effect of the field becomes more and more noticeable.

Electric field is a vector quantity whose direction is defined as the direction that a positive test charge would be pushed when placed in the field. Thus, the electric field direction about a positive source charge is always directed away from the positive source. And the electric field direction about a negative source charge is always directed toward the negative source.

Direction of an Electric Field

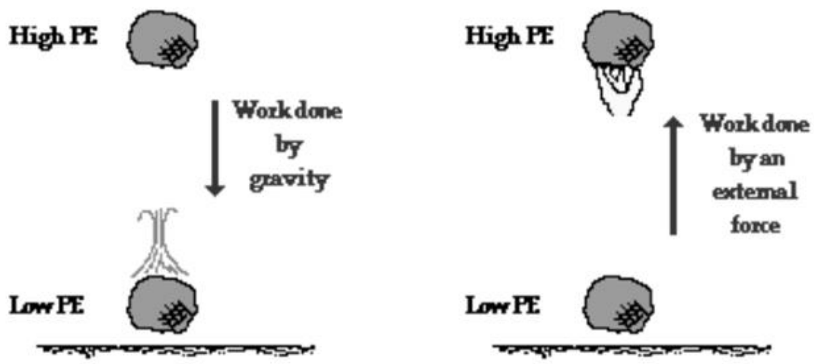


Adapted from https://www/physicsclassroom.com/class/estatics/Lesson-4/Electric-Field-Intensity

Figure 9. The electric field direction is always directed away from positive source charges and towards negative source charges

Electric Field, Work, and Potential Energy

Electric fields are similar to gravitational fields - both involve action-at-a-distance forces. In the case of gravitational fields, the source of the field is a massive object and the action-at-a-distance forces are exerted upon other masses. In addition, the force of gravity is an internal or conservative force. When gravity does work upon an object to move it from a high location to a lower location, the *object's total amount of mechanical energy is conserved*. However, during the course of the falling motion, there was a loss of potential energy (and a gain of kinetic energy). When gravity does work upon an object to move it in the direction of the gravitational field, then the object loses potential energy. The potential energy originally stored within the object as a result of its vertical position is lost as the object moves under the influence of the gravitational field. On the other hand, energy would be required to move a massive object against its gravitational field. A stationary object would not naturally move against the field and gain potential energy. Energy in the form of work would have to be imparted to the object by an external force in order for it to gain this height and the corresponding potential energy.



Adapted from https://www/physicsclassroom.com/class/estatics/Lesson-4/Electric-Field-Intensity

The important point to be made by this gravitational analogy is that work must be done by an external force to move an object against nature - from low potential energy to high potential energy. On the other hand, objects naturally move from high potential energy to low potential energy under the influence of the field force. It is simply natural for objects to move from high energy to low energy; but work is required to move an object from low energy to high energy.

In a similar manner, to move a charge in an electric field against its natural direction of motion would require work. The exertion of work by an external force would in turn add potential energy to the object. The natural direction of motion of an object is from high energy to low energy; but work must be done to move the object against nature. On the other hand, work would not be required to move an object from a high potential energy location to a low potential energy location. When this principle is logically extended to the movement of charge within an electric field, the relationship between work, energy and the direction that a charge moves becomes more obvious.

The Force per Charge Ratio

Electric field strength is a vector quantity; it has both magnitude and direction. The magnitude of the electric field strength is defined in terms of how it is measured. Let's suppose that an electric charge can be denoted by the symbol ***Q***. This electric charge creates an electric field; since **Q** is the source of the electric field, we will refer to it as the **source charge**. The strength of the source charge's electric field could be measured by any other charge placed somewhere in its surroundings. The charge that is used to measure the electric field strength is referred to as a **test charge** since it is used to *test* the field strength. The test charge has a quantity of charge denoted by the symbol ***q***. When placed within the electric field, the test charge will experience an electric force - either attractive or repulsive. As is usually the case, this force will be denoted by the symbol ***F***. The magnitude of the electric field is simply defined as the force per charge on the test charge.

$$\boldsymbol{Electric\ Field\ Strength} = \frac{\boldsymbol{Force}}{\boldsymbol{Charge}}$$

If the electric field strength is denoted by the symbol ***E***, then the equation can be rewritten in symbolic form as

$$\boldsymbol{E} = \frac{\boldsymbol{F}}{\boldsymbol{q}}$$

. The standard metric units on electric field strength arise from its definition. Since electric field is defined as a force per charge, its units would be force units divided by charge units. In this case, the standard metric units are *Newton/Coulomb or N/C.*

Another Electric Field Strength Formula

The above discussion pertained to defining electric field strength in terms of how it is measured. Now we will investigate a new equation that defines electric field strength in terms of the variables that affect the electric field strength. To do so, we will have to revisit the Coulomb's law equation. **Coulomb's law** states that the *electric force between two charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between their centers.* When applied to our two charges - the source charge (**Q**) and the test charge (**q**) - the formula for electric force can be written as

$$F = \frac{k \cdot q \cdot Q}{r^2}$$

where k = 8.99 x 10^9 $N \cdot m^2/C^2$ (constant value)
r = separation distance between charges (meters)

If the expression for electric force as given by Coulomb's law is substituted for force in the above *E = F/q* equation, a new equation can be derived as shown below.

$$E = \frac{F}{q} = \frac{k \cdot \cancel{q} \cdot Q/r^2}{\cancel{q}} = \frac{k \cdot Q}{r^2}$$

$$E = \frac{k \cdot Q}{r^2}$$

Note that the derivation above shows that the test charge **q** was canceled from both numerator and denominator of the equation. The new formula for electric field strength expresses the field strength in terms of the two variables that affect it. The electric field strength is dependent upon the quantity of charge on the source charge (**Q**) and the distance of separation (***r***) from the source charge.

In addition, the above equation shows that $\boldsymbol{E}$ is the electric field, $\boldsymbol{Q}$ is the source charge, and $\boldsymbol{r}$ is the distance from the source charge where the electric field is being measured. The unit used to measure electric field is *Newton per Coulomb (N/C)*. The source charge is the charge from where the electric field comes from. In simpler terms, you determine how the test charge will behave as the result of the electric field coming from the source charge.

$$E = \frac{F_E}{q}$$

In this equation, $\boldsymbol{F_E}$ is the electrostatic force experienced by the electric charge. An electric field is also a vector quantity. It has the same direction as the electrostatic force exerted on an electric charge.

Note that the derivation above shows that the test charge **q** was canceled from both numerator and denominator of the equation. The new formula for electric field strength expresses the field strength in terms of the two variables that affect it. The electric field strength is dependent upon the quantity of charge on the source charge (**Q**) and the distance of separation (**r**) from the source charge.

Sample Problem 1:

- Calculate the electric field that a test charge will experience on the following distances from the source charge of +5.02 x 10^{-13} C.
    a. Distance from source charge: 2.04 x 10^{-3} m

Solution: $\mathrm{E} = \frac{kQ}{r^2}$

$$\mathrm{E} = \frac{\left(8.99x10^9 \frac{N \cdot \cancel{m^2}}{\cancel{C^2}}\right)(5.02X10^{-13}\cancel{C})}{(2.04x10^{-3}\cancel{m})^2} \approx \mathbf{1084.43\ N/C}$$

The source charge will experience an electric field of approximately 1084.43 N/C.

b. Distance from source charge: 1.55 x 10^{-12} m

Solution: $\mathrm{E} = \frac{kQ}{r^2}$

$$\mathrm{E} = \frac{\left(9x10^9 \frac{N \cdot \cancel{m^2}}{\cancel{C^2}}\right)(5.02X10^{-13}\cancel{C})}{(1.55x10^{-12}\cancel{m})^2} \approx \mathbf{1.88\ x\ 10^{21}\ N/C}$$

The source charge will experience an electric field of approximately 1.88 x 10^{21} N/C.

Sample Problem 2:

Compute the electric field experienced by a test charge q = +0.80 μC from a source charge q = +15 μC in a vacuum when the test charge is placed 0.20 m away from the other charge.

Solution:

The magnitude of the electrostatic force between the two charges is determined as follows:

$$F_E = \frac{\left(8.99x10^9 \frac{N \cdot \cancel{m^2}}{\cancel{C^2}}\right)(0.8X10^{-6}\cancel{C})(15X10^{-6}\cancel{C})}{(0.20\ \cancel{m})^2} \approx 2.7\ N$$

The magnitude of the electric field is computed using

$$E = \frac{F_E}{q} \approx \frac{2.7\ N}{0.8\ x\ 10^{-6}\ C} \approx 3.4\ x\ 10^6\ N/C$$

The test charge experiences an electric field of approximately 3.4 x 10^6 N/C.

Electric Flux

In order to understand Gauss's Law, first we need to understand the term Electric flux.

Electric flux is the rate of flow of the electric field through a given surface.

It is the amount of electric field penetrating a surface. And that surface can be open or closed.

Electric Flux Through Open Surfaces

First, we'll take a look at an example for electric flux through an open surface.

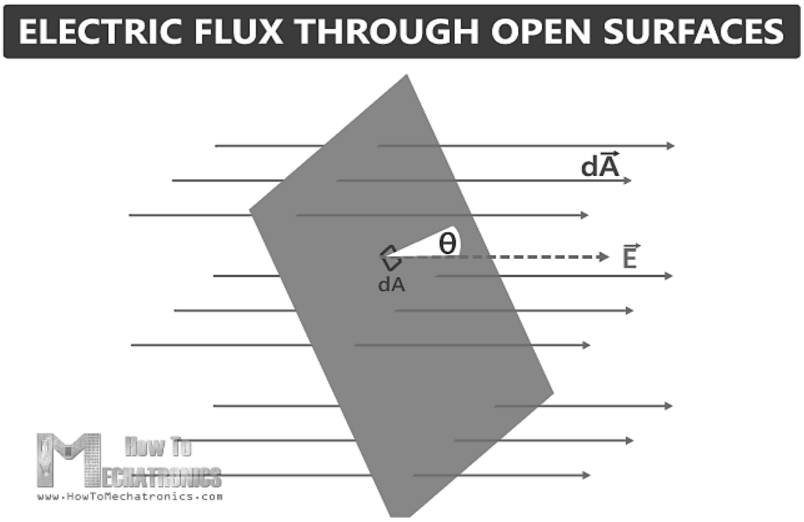


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Figure 10. Electric Flux through open surfaces

The red lines represent a uniform electric field. We will bring in that field a rectangle, which is an open area, and we will divide it into very small elements, each with size *dA* (differential of area).

Now we're going to make the area *dA* a vector, with a magnitude *dA*. The vector direction is always perpendicular to the small element *dA*.

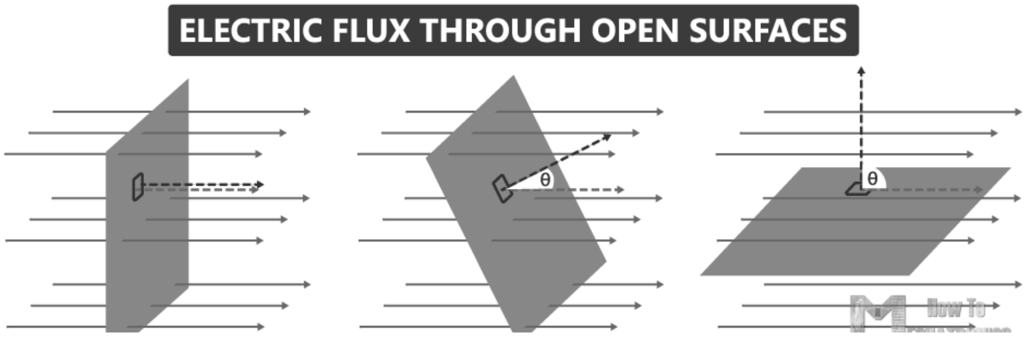
$$d\Phi = \vec{E} \cdot d\vec{A}$$
$$d\Phi = EdAcos\theta$$

The electric flux that passes through this small area *dφ,* (also called a differential of flux), is defined as a dot product of the magnitude of the electric field E and the magnitude of the vector area dA, times the angle between these two vectors θ.

It is a scalar quantity and the end result can be **positive** or **negative**. If the flux is going from the inside to the outside, we call that a positive flux, if it is going from the outside to the inside, that's a negative flux.

$$[\Phi] = \left[\frac{Nm^2}{C}\right]$$

**The unit of electric flux is Newton meters squared per Coulomb (Nm2/C)*



Retrieved from https://howtomechatronics.com/wp-content/uploads/2018/09/5.Electric-Flux-and-Gausss-Law-3-Rectangles-with-Different-Orientation-into-an-Electric-Field.png

Figure 11. Rectangle with Different Orientation into an Electric Field

To get a better understanding of what electric flux is, let us examine this electric field three rectangles. In fact, these rectangles represent one rectangle with different orientations. Now let's explain the flux through each one of those open areas.

In the first case, the area is perpendicular to the electric field, and the angle between their vectors θ is 0°. *Cos0°* is 1, so the electric flux is going to be *EdA*. Here we have **maximum flux**.

$$d\Phi = EdAcos\theta$$

$$d\Phi = EdAcos60°$$

$$d\Phi = \frac{EdA}{2}$$

In the second case, the angle between E and dA θ is 60°, and cos60° is 0.5, so the electric flux will be half *EdA*.

$$d\Phi = EdAcos\theta$$

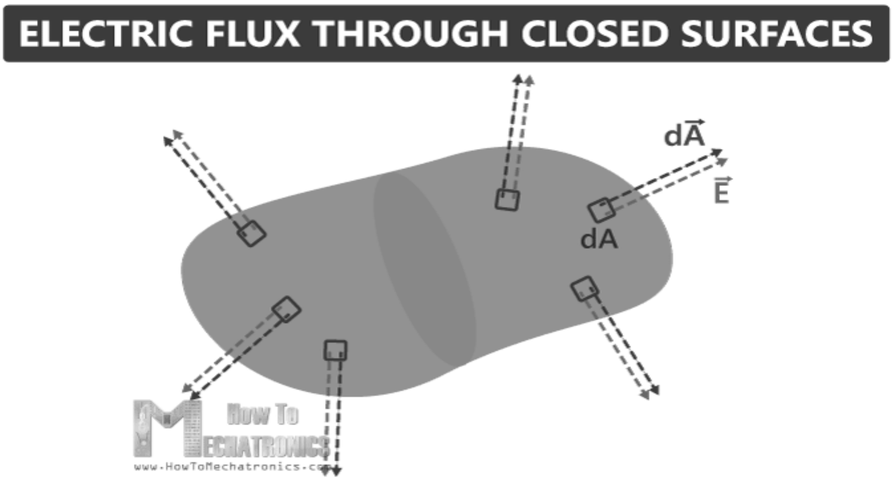
$$d\Phi = EdAcos90°$$

$$d\Phi = 0$$

In the third case, the area is parallel to the electric field, which means that their vectors are perpendicular to each other, and the angle θ between them is 90°. Cos 90° is 0, so the electric flux here will be 0. This means that nothing goes through that rectangle, so here we have **zero flux**.

Electric Flux Through Closed Surfaces

Now, let's take a look at a surface that is completely closed.



Retrieved from https://howtomechatronics.com/wp-content/uploads/2018/09/9.Electric-Flux-and-Gausss-Law-Electric-Flux-through-

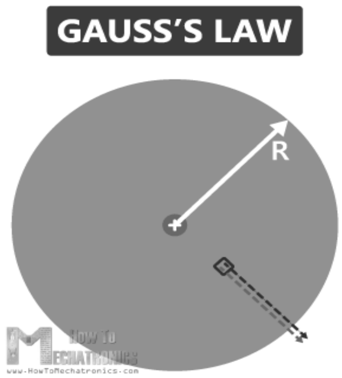
Figure 12. Electric Flux and Gauss Law Electric Flux through Closed

How do we define flux?

Here, we put some normal, *dAs* in different directions. By convention, the normal to the closed surface always points from the inside to the outside.

The total flux can be positive, negative, or equal to zero. If the same amount of flux is entering and leaving the surface, we have **zero total flux**. If more flux is leaving than entering the surface, then we have **positive total flux**. Opposite, if more flux is entering than leaving the surface, we have a **negative total flux**.

Let's take a look at another example and see how the electric flux is related to Gauss's Law.



Retrieved from https://howtomechatronics.com/wp-content/uploads/2018/09/11.Electric-Flux-and-Gausss-Law-Point-Charge-in-the-Center-of-a-Sphere-251x300.png

Figure 13. Electric Flux and Gauss Law Point Charge in the Center of a Sphere

We have a point charge +Q in the center of a sphere with radius *R*. Now, we'll take a small segment *dA,* which vector is perpendicular to the surface and is radially outward. The electric field generated by Q at that point is also radially outward. This means that *dA* and *E* anywhere on the surface of this sphere are parallel to each other, the angle between them θ is 0°, and cos0° is 1.

$$d\Phi = EdA$$

The magnitude of the electric field everywhere is the same because the distance from the charge is the same at each point.

The total area of the sphere *A* is $4\pi R^2$.

$$E = k\frac{Q}{R^2} = \frac{1}{4\pi E_0}\frac{Q}{R^2}$$

From the previous discussion we know that *E* is equal to *k* times Q divided by r^2, which is equal to Q divided by $4\pi E_0 R^2$.

$$\Phi = \frac{Q}{4\pi E_0 R^2}\,4\pi R^2 = \frac{Q}{E_0}$$

And the total flux through this closed surface is simply *E* times $4\pi R^2$. Here we can cancel out $4\pi R^2$, and we can notice that the total flux is equal to Q divided by E_0, where E_0 is permittivity of free space.

The flux doesn't depend on the distance *r*. We would get the same result no matter the size of the closed surface around the point charge.

What if we bring more charges inside the closed surface?

The equation should also hold for any system of charges inside.

$$\Phi = \frac{\sum Q_{enclosed}}{E_0}$$

This leads us to the Gauss's Law, which says that the electric flux going through a closed surface, is the sum of all charges Q inside that closed surface, divided by permittivity of free space E_0.

If that flux is zero, that means there is no net charge inside the shape. There could be positive and negative charges inside the shape, but the net is zero.

No matter how weird the shape, Gauss's Law always holds, as long as there's symmetry in the charge distribution inside the surface.

Using Gauss' Law to Calculate Electric Fields

Even though charge is quantized, we often can treat it as being continuously distributed inside some volume, since one quantum of charge is a tiny amount of charge. On a macroscopic scale we define:

volume charge density as the charge per unit volume

$$\rho = \lim_{\Delta V \to 0}(\Delta Q/\Delta V)$$

surface charge density as the charge per unit area

$$\sigma = \lim_{\Delta A \to 0}(\Delta Q/\Delta A)$$

line charge density as the charge per unit length

$$\lambda = \lim_{\Delta L \to 0}(\Delta Q/\Delta L)$$

Electric Field for a Uniform Sphere of Charge

Imagine a sphere of radius *R* with charge *Q* uniformly distributed inside. The symmetry of the charge distribution requires a spherically symmetric electric field. The field must either point radially inward toward the center or outward from the center of the sphere. (If we have a spherically symmetric charge distribution, then, no matter how we orient our coordinate system, the distribution always looks the same. The field therefore also must look the same, no matter how we orient our coordinate system. A field that is not radial will look different if we rotate our coordinate system, i.e. if we look at it from another angle.)

For a spherical symmetric charge distribution, the magnitude of ***E*** can therefore only depend on the radial coordinate r and on the charge Q. To determine *E* as a function of *r,* we use Gauss' law. We draw a spherical **Gaussian surface** of radius *r* centered at the center of the spherical charge distribution. The radius *r* of the surface can be larger or smaller than the radius *R* of the distribution.

Let *r* be greater than *R*, so that the surface encloses the entire charge distribution. The electric field is radial, the vector ***E*** is normal to any surface element *dA.*

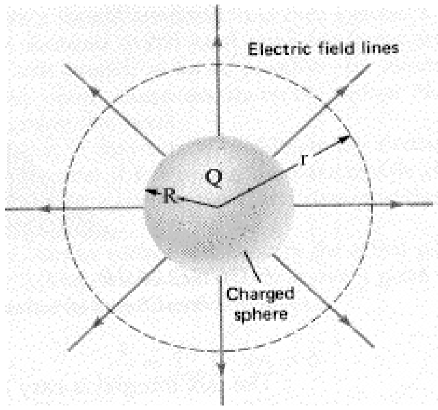


Figure 14

Thus

$\Phi_E = E\ 4\pi r^2 = Q_{inside}/\varepsilon_0 = Q/\varepsilon_0$

from Gauss' law. We therefore have

$\mathbf{E} = Q/(4\pi\varepsilon_0 r^2)\mathbf{n}.$

The field outside a uniformly distributed spherically symmetric charge distribution looks like the field of a point charge. If Q is positive, the field points outward, and if Q is negative, it points inward. Q_{inside} can be written as the charge density $\rho = Q/V$ times the volume of the charged sphere $V = 4\pi R^3/3$. We can therefore also write

$\mathbf{E} = \rho R^3/(3\varepsilon_0 r^2)\mathbf{n}.$

Let *r* be smaller than *R*, so that the surface only encloses a part of the charge distribution. Now Q_{inside} is the charge density $\rho= Q/V$ times the volume $4\pi r^3/3$ of the distribution which lies inside the spherical Gaussian surface. We therefore have

$$\mathbf{E} = \rho r/(3\varepsilon_0)\mathbf{n}.$$

The field inside the uniformly distributed spherically symmetric charge distribution increases linearly with *r.* Its direction is outward for a positive distribution, and inward for a negative distribution.

Electric Field Near an Infinite Plane of Charge

For an infinite plane of charge lying in the x-y plane, with its normal parallel to the z-axis, the field cannot depend on x or y. (If we shift the origin of our coordinate system along the x- or y-axis, or rotate our coordinate system about the z-axis, the charge distribution looks the same. The field must therefore also look the same.) The field must therefore be parallel to the z-axis. The field must also be symmetric under reflection about the x-y plane. This means that the field must have the same magnitude at +z as it has at -z, but that it must point in opposite directions at +z and at -z.

For our Gaussian surface we can choose a simple right circular cylinder with faces parallel to the plane of charge. The field lines are parallel to the sides of the cylinder, so the sides do not contribute to the flux. The flux through the top surface is *EA* and the flux through the bottom surface is *EA*. (On the top, both ***E*** and ***n*** point upward, and on the bottom both ***E*** and ***n*** point downward.) Gauss' law yields,

$$\Phi_{E\ net} = 2EA = Q_{inside}/\varepsilon_0.$$

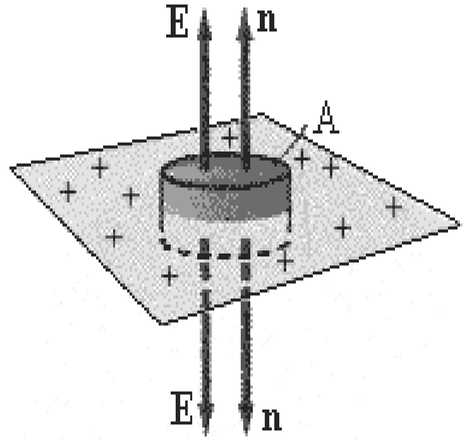


Figure 15

If the surface charge density is σ, the $Q_{inside} = \sigma A$, and $\Phi E\ nett = 2EA = \sigma A/\varepsilon_0$, and $E = \sigma/2\varepsilon_0$.

The field of an infinite planar charge distribution is uniform. It does not decrease with distance. Of course, there are no infinite sheets of charge. But our result is a good approximation to the field near a finite-size plane of charge, as long as the dimensions of the plane are much larger than the distance away from the plane where we want to know the field.

The most important application of the above result is the superposition of the fields from two planar charge distributions which are separated by some distance *d*. Place a uniformly charged plane with charge density σ at $x = +d/2$ and a similar plane with charge density $-\sigma$ at $x = -d/2$.

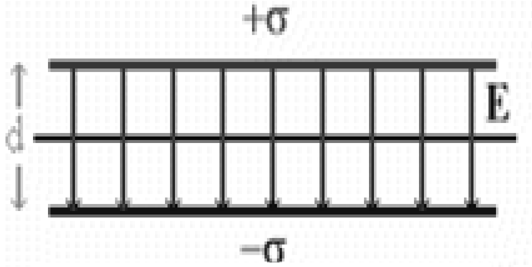


Figure 16

The field due to the upper plane of charge is
$E_1 = \sigma/2\varepsilon_0$, $x > d/2$, $E_1 = -\sigma/2\varepsilon_0$, $x < d/2$.

The field due to the lower plane of charge is
$E_2 = \sigma/2\varepsilon_0$, $x < -d/2$, $E_2 = -\sigma/2\varepsilon_0$, $x > -d/2$.

The total field in the region $x < -d/2$ is $E = E_1 + E_2 = -\sigma/2\varepsilon_0 + \sigma/2\varepsilon_0 = 0$.
Similarly, the total field in the region $x > d/2$ is zero.
In the region between $-d/2$ and $+d/2$ the total field is
$E = E_1 + E_2 = -\sigma/2\varepsilon_0 - \sigma/2\varepsilon_0 = -\sigma/\varepsilon_0$.

The fields add to yield a uniform field between the planes, but they precisely cancel outside the planes to give zero net field outside. Between the planes the field points from the positive towards the negative plane. This is the common configuration of a parallel plate capacitor.

Example 3:

A sphere of radius $R = 40cm$ has a total positive charge of 26 micro C uniformly distributed over its surface.

Calculate the magnitude of the electric field at:
(a) 0 cm,
(b) 30 cm, and
(c) 60 cm from the center of the sphere.

The symmetry of the charge distribution requires a spherically symmetric electric field. The field will point radially away from the center of the positive charge distribution and its magnitude will only depend on the distance r from the center. If we draw a spherical Gaussian surface of radius r centered at the center of the spherical charge distribution, then Gauss' law gives the flux of the electric field through this surface as

$$\Phi_E = E\ 4\pi r^2 = Q_{inside}/\varepsilon_0.$$

The charge inside a sphere of radius r is $Q_{inside} = \rho V(r) = \rho 4\pi r^3/3$, where the charge density $\rho = Q/(4\pi R^3/3)$.

(a) From Gauss' law we have

$E(r) = Q/(4\pi\varepsilon_0 r^2)$ for $r > R$,
and $E(r) = \rho r/(3\varepsilon_0)$ for $r < R$.
At $r = 0$ we have $E(r) = 0$.

(b) We have $\rho(r) = 0$ inside the sphere,
therefore $E(r) = 0$ inside the sphere.

(c) At r = 0.6 m
we have $E(r) = Q/(4\pi\varepsilon_0 r^2)$
$= (9*10^9*2.6*10^{-5}/(0.6)^2)(N/C)$
$= 6.5*10^5$ N/C.

Example 4:
A uniform electric field *E = 8000 N/C* passing through a flat square area *A = 10 m²*. Determine the electric flux.

Given:
The magnitude of the electric field (E) = 8000 N/C
Area (A) = 10 m^2
q = 0° (the angle between the electric field direction and a line drawn a perpendicular to the area)

Unknown: Electric flux (Φ)

Solution:
The formula of electric flux:
$\Phi = \mathrm{E\ A\ cos\ q}$

where:
Φ = electric flux (Nm^2/C), E = electric field (N/C), A = area (m^2), q = angle between electric field line with the normal line.

Electric flux:
Φ = E A cos q
= (8000 N/C)(10m^2)(cos 0)
= (8000 N/C)(10m^2)(1)
= 80,000
= 8 x 10^4 Nm^2/C

Example 5:
A uniform electric field *E = 5000 N/C* passing through a flat square area *A = 2 m^2*. Determine the electric flux.

Given:
Electric field (E) = 5000 N/C
Area (A) = 2 m2
θ = 60° (the angle between the electric field direction and a line drawn perpendicular to the area)

Unknown: Electric flux (Φ)

Solution:

Φ = E A cos q

= (5000N/C)(2m^2)(cos 60)

= (5000 N/C)(2 m^2)(0.5)

= 5000 Nm^2/C

= 5 x 10^3 Nm^2/C

Performance Task:

TRY THIS OUT!

Directions: Perform the activity below. After which, answer the guide questions that follow. Write your answers on your notebook/Answer Sheet.

Task 1: Rub a comb through your hair and use it to lift pieces of paper. Tear the pieces of paper rather than cut them neatly. Repeat the exercise in your bathroom after you have had a long shower and the air in the bathroom is moist.

1. Is it easier to get electrostatic effects in dry or moist air?
2. Why would torn paper be more attractive to the comb than cut paper? Explain your observations.

Task 2: Write one situation showing the following conditions (10 points).

a. Charging by rubbing
b. Charging by induction

III. WHAT I HAVE LEARNED
EVALUATION/POST-TEST:

I. MULTIPLE CHOICE: Read each question carefully. Write your answers on your notebook/Answer Sheet. Show your solutions for items that require such.

1. Find the flux through a spherical Gaussian surface of radius a = 1 m surrounding a charge of 8.85 pC.
   a. 1 x 10^{-16}N m^2 /C c. 1 x 10^{-8} N m^2 /C
   b. 1 x 10^{-12} N m^2 /C d. 1 N m^2 /C
2. A positive charge Q=8 mC is placed inside the cavity of a neutral spherical conducting shell with an inner radius *a* and an outer radius *b*. Find the charges induced at the inner and outer surfaces of the shell.
   a. Inner charge = –8 mC, Outer charge = +8 mC
   b. Inner charge = +8 mC, Outer charge = -8 mC
   c. Inner charge = 0 mC, Outer charge = +8 mC
   d. Inner charge = –8 mC, Outer charge = 0 mC

3. A positive charge Q=8 mC is placed inside a spherical conducting shell with inner radius *a* and outer radius *b* which has an extra charge of 4 mC placed somewhere on it. When all motion of charges ends (after 10-15 sec), find the charges on the inner and outer surfaces of the shell.
   a. Inner charge = –8 mC, Outer charge = +8 mC
   b. Inner charge = +8 mC, Outer charge = -8 mC
   c. Inner charge = +8 mC, Outer charge = -12 mC
   d. Inner charge = –8 mC, Outer charge = 12 mC
4. Find the value of the electric field at a distance r=10 cm from the center of a non-conducting sphere of radius R=1 cm which has an extra positive charge equal to 7 C uniformly distributed within the volume of the sphere.
   a. 6.3×10^{12} N/C
   b. 1.2 x 100 N/C
   c. 7.5×10^{-6} N/C
   d. 9.1×10^{-3} N/C
5. A positive charge is placed inside a spherical metallic shell with inner radius *a* and outer radius *b*. The charge is placed at shifted position relative to the center of the shell. Describe the charge distribution induced at the shell surfaces.
   a. A negative charge with uniform surface density will be induced on the inner surface; a positive charge will be induced on the outer surface.
   b. A negative charge with non-uniform surface density will be induced on the inner surface; a positive charge will be induced on the outer surface.
   c. A positive charge with uniform surface density will be induced on the inner surface, a negative charge will be induced on the outer surface.
   d. A positive charge with non-uniform surface density will be induced on the inner surface; a negative charge will be induced at the outer surface.

II. TRUE OR FALSE: Write ***T*** if the statement is correct and ***F*** if incorrect. Write your answers on your notebook/Answer Sheet.

________1. If a charged object touches a conductor, some charge will be transferred between the object and the conductor, charging the conductor with the same sign as the charge on the object.

_______ 2. Charging by induction is also useful for charging metals and other conductors.

_______ 3. The ancient Greeks discovered as early as 600 B.C. that after they rubbed amber with wool, the fur could attract other objects.

_______ 4. Two positive charges or two negative charges attract each other.

_______ 5. Like charges attract while unlike charges repel.

_______ 6. Electrostatic painting employs electrostatic charge to spray paint onto odd-shaped surfaces.

_______ 7. Electric field is a vector quantity whose direction is defined as the direction that a positive test charge would be pushed when placed in the field.

_______ 8. A charged object creates an electric field - an alteration of the space or field in the region that surrounds it.

_______ 9. Neutral objects can be attracted to any charged object.

_______10. Any substance that has free electrons and allows charge to move relatively freely through it is called a conductor.

III. **PROBLEM SOLVING:** Read and answer the given problems below. Show your solutions and write them in your notebook/Answer Sheet.

1. Find (a) magnitude of the electric field 0.5 m from a 2.5 -μC point charge and (b) the magnitude and direction of the electrostatic force acting on an electron placed at that point.
   a. *Given:*
   b. *Formula:*
   c. *Solution*
   d. *Final Answer with unit:*
2. Find the electric field midway between a 2 -μC point charge which are 2.5 m apart.
   a. *Given:*
   b. *Formula:*
   c. *Solution*
   d. *Final Answer with unit:*

REFERENCES

Bulos, E, et.al. Worktext in Electromagnetism. Lectric Field.p.9-10.

CHED K to 12 Senior High School Teaching Guides. Retrieved from https://chedk12.wordpress.com/teachingguides

David, Oliver M. *General Physics 2*. Makati City, Philippines: DIWA Learning Systems Inc., 2017.

Dejan. Retrieved from https://howtomechatronics.com/learn/electricity/electric-flux-gausss-law/

Electric Field: Concept of a Field Revisited. Retrieved from https://courses.lumenlearning.com/physics/chapter/18-4-electric-field-concept-of-a-field-revisited

Electric flux – Problems and Solutions. Retrieved from https://physics.gurumuda.net/electric-flux-problems-and-solutions.htm

file:///E:/BOOKS/Sears%20&%20Zemansky%20University%20Physics%20with%20Modern%20Physics%2013e.

Gauss' law. Retrieved from http://labman.phys.utk.edu/phys222core/modules/m1/Gauss'%20law.html

K to12 Most Essential Learning Competencies with corresponding CG Codes. Retrieved from https://commons.deped.gov.ph/K-to-12-MELCS-with-CG-Codes.pdf

Lumen: Boundless Physics. Retrieved from https://courses.lumenlearning.com/boundless-physics/chapter/electric-flux-and-gausss-law/#:~:text=In%20words%2C%20Gauss's%20law%20states,enclosed%20within%20that%20closed%20surface

Physics Tutorial: Electric Field Intensity. Retrieved from https://www/physicsclassroom.com/class/estatics/Lesson-4/Electric-Field-Intensity

Urone, Paul Peter and Hinrichs, Roger. *College Physics*. 6100 Main Street MS–375 Houston, Texas 77005: College Physics., 2012.

http://physics.bu.edu/~duffy/PY106/Charge.html

https://courses.lumenlearning.com/physics/chapter/18-8-applications-of-electrostatics/

https://www.sciencedirect.com/topics/chemistry/electrostatic-charge#:~:text=1%20Electrostatic%20charges,through%20a%20copier%20or%20printer

https://mcqlearn.com/physics/g10/electric-charge-mcqs.php

https://www.physicsclassroom.com/class/circuits/Lesson-1/Electric-Field-and-the-Movement-of-Charge

https://web.njit.edu/~janow/Physics%20121%20Spring%202020/Review%20Material/Common%20Exam%201/Common%201%20Problem%20Solutions%20and%20Notes.pdf

https://chedk12.wordpress.com/teachingguides

https://web.njit.edu/~janow/Physics%20121%20Spring%202020/Review%20Material/Common%20Exam%201/Common%202%20Problem%20Solutions%20and%20Notes.pdf

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SYNOPSIS AND ABOUT THE AUTHORS

Knowledge on electric and electrostatic charges is very significant because it shows how electron transfer played the role in electric charging. This is incredibly valuable for scientists, engineers, inventors and most especially for teachers and learners.

An electric field is a region of space around an electrically charged particle or object in which an electric charge would feel force.

An electric field is a vector quantity and can be visualized as arrows going toward or away from charges. The lines are defined as pointing radially outward, away from a positive charge, or radially inward, toward a negative charge.

Coulomb's law: For charges q_1 and q_2 separated by a distance r, the magnitude of the electric force on either charge is proportional to the product q_1q_2 and inversely proportional to r^2. The force on each charge is along the line joining the two charges—repulsive if q_1 and q_2 have the same sign, attractive if they have opposite signs. In SI units the unit of electric charge is the coulomb, abbreviated C.

When two or more charges each exert a force on a charge, the total force on that charge is the vector sum of the forces exerted by the individual charges.

Gauss's law is one of the four Maxwell's equations which form the basis of classical electrodynamics. Gauss's law can be used to derive Coulomb's law, and vice versa. Gauss's law states that: The net outward normal electric flux through any closed surface is proportional to the total electric charge enclosed within that closed surface.

ANSWER KEY

Pre–Test:

1. d	11. c
2. c	12. c
3. c	13. a
4. b	14. b
5. a	15. a
6. b	16. b
7. c	17. c
8. c	18. a
9. a	19. a
10. a	20. c

Post–Test:

I. Multiple Choice:	II. True or False:
1. d	1. T
2. a	2. T
3. d	3. F
4. a	4. F
5. b	5. F
	6. T
	7. T
	8. T
	9. T
	10. T

III. Problem Solving:

1. a. $8.99 \, x \, 10^4 \, N/C$
   b. $1.44 \, x \, 10^{-14} \, N$
2. $2.88 \, X \, 10^4 \, N/C \; towards \; the - 3\mu C$

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