Grade 12 physics V2

SPH4U

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Contents

Chapter 1

Electricity and Magnetism

1.1 Review of Electronstatics

In this section, we will briefly review basic Electronstatics which we learned from Grade 9 Science

1.1.1 Electric Charge

Electron

By the early 1900s, physicists had identified the subatomic particles called the electron and the proton as the basic units of charge. All protons carry the same amount of positive charge, e, and all electrons carry an equal but opposite charge, $-e$. Charges interact with each other in very specific ways governed by the **law of electric charges**

Theorem 1.1.1 (Law of Electric Charges)
Like charges repel each other; unlike charges attract.

Charge of atom

Cation: a positive ion. # of protons > # of electrons
Anion: a negative ion. # of protons < # of electrons

The **Total Charge** is the sum of all the charges in that object and can be positive, negative or zero. The charge is equal to zero when the negative charge equals to negative charge.

Theorem 1.1.2 (Law of Conservation of Charge)
Charge can be transferred from one object to another, but the total charge of a closed system remains constant.

Coulomb

The basic unit of charge is called the coulomb (C). The charge of electron, $-e$, is $-1.60 * 10^{-19}C$, and the charge of a single proton, $+e$, is $1.60 * 10^{-19}C$

Symbol e often donotes the magnitude of the charge of an electron or a proton.

The symbol q denotes teh amount of charge, such as the total charge onf a small piece of paper. In other words, the total charge of a particle is q.

1.1.2 Conductors and Insulators

Definition 1.1.3 (Conductor)
A conductor is a substance in which electrons can move easily among atoms.

Definition 1.1.4 (Insulator)
any substance in which electrons are not free to move easily from one atom to another.

Insulator hold the electron when other electron come in. There are no free electrons in the insulator, and insulator does not allow the extra electrons to move about easily.

1.1.3 Different methods of charging

Charging an Object by Friction

In reality, some object has stronger ability to hold on electrons than others. Assume we have two neutral object, when these two objects touch, electrons will follow from the object with weaker hold on electrons to the other one with stronger hold on electrons.

Carging an object by Induced Charge Separation

Assume we have two objects, one with zero charge and other one with negative charge. When we put the negative object towards the positive object, electrons in the neutral object will repel to the electrons in the negative object. As a result, electrons in the neutral object will redistributed throughout the material. The positive side of the netural object is closer than the negative side of the object, in which makes the neutral object attract to the negative object.

Charging by Contact

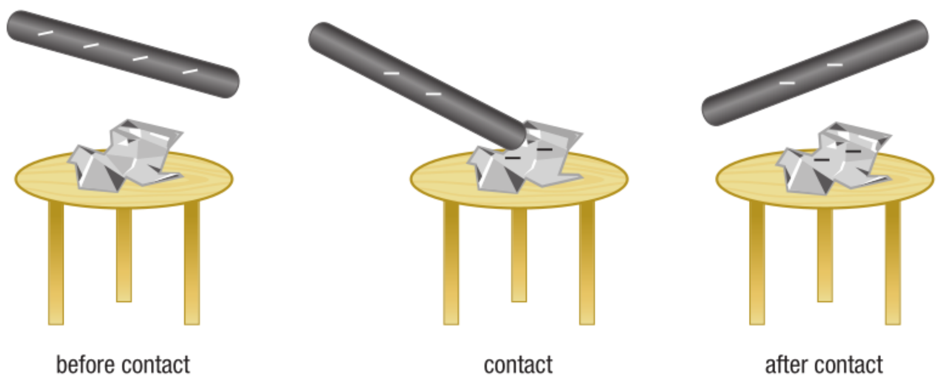


Figure 1.1: Picture from my textbook

Charging by Induction

Using a negative object to create a positive object

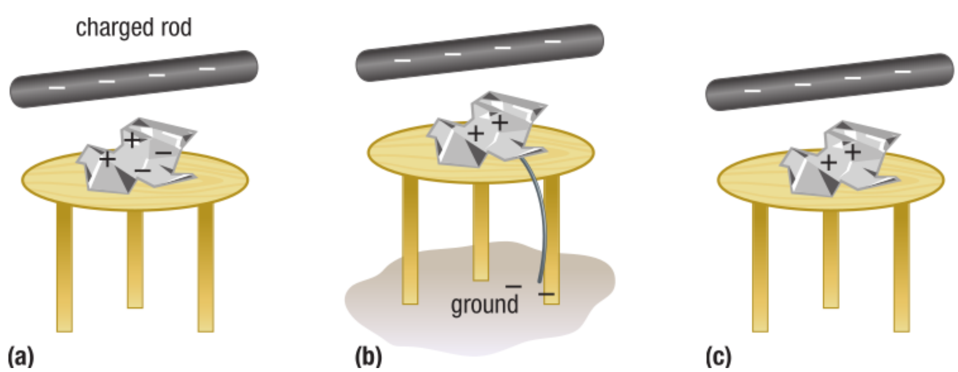


Figure 1.2: Picture from my textbook

1.2 Coulomb's Law

1.2.1 Background

Coulomb was a scientist who studied electricity in the early 1800's. He wanted to find out what factor affect the electrostatic force with two charged objects.

Coulomb based his experiment on Carendish's experiment.

To be able to perform the experiment Coulomb needed to electrically charge each of the pith balls and know the magnitude of the charge on each bal. His solution for this was to find the relative magnitude of the charge on each pith ball.

1.2.2 Formula

By measuring the amount of force, the separation distance between the charged objects and the relative charge of the pith balls, Coulomb was abl to find the following relationships:

$$F_E \propto \frac{1}{R^2}$$
$$F_E \propto q_1 q_2$$

We can bring these proportionalities together:

$$|F_E| = \frac{k\,|q_1|\,|q_2|}{R^2}$$

F_E is the magnitude of the electrical force in between two point charges
q_a and q_b is the absolute value of the charge of each object (in C)
R is the separation distance betweeen the objects (in m)
k is Coulomb's law constant of proportionality ($k = 8.99 \times 10^9 \frac{Nm^2}{C^2}$)

Remark. When using equations for electrical forces, don't substitute in the sign of the charge. Find the direction of the force conceptually!

1.3 Electric Fields

Definition 1.3.1 (Field)
The region where an appropriate object would feel a force!

- If there's a gravitational field, a mass will feel a force.
- If there's an electric field, a charge will feel a force.
- If there is an magnetic field, a magnet (or a moving charge) will feel a force.

Visualizing Electric Fields - Field lines show how a small positive charge would move.

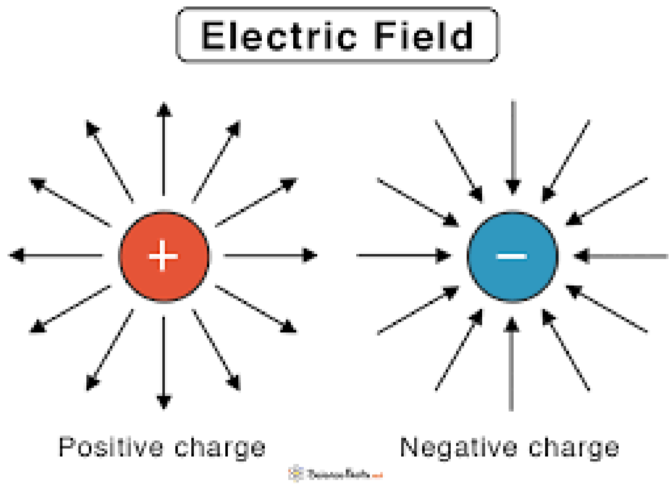


Figure 1.3: Electric field of Positive and negative charge

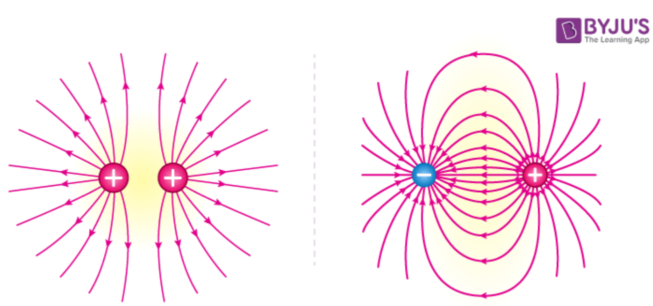


Figure 1.4: Electric field between two charges

Formulas

$$\mathcal{E} = \frac{k\,|q|}{R^2} \tag{1.1}$$

$\mathcal{E}$ is the magnitude of the electric field strength around a point charge (in $\frac{N}{C}$)

$k = 8.99 \times 10^9 \frac{Nm^2}{C^2}$

R is the distance away from the point charge (q) where you want to know the field strength (in m)

Remark. Electric fields are vector. The direction of the field will be based on the direction of force that would be exerted on a positively-charged object!

$$\vec{F_E} = q \times \vec{\mathcal{E}} \tag{1.2}$$

$\vec{F_E}$ is the magnitude of the electrical force exerted on q (in N)
q is the that is in the electric field(in C)
$\vec{\mathcal{E}}$ is the strength of the electrical field that the charge is in (in $\frac{N}{C}$)

1.4 Electric Potential Energy & Electric Potential

1.4.1 Electric Potential Energy

Definition 1.4.1 (Electric Potential Energy)
The energy stored in a system of two or more objects due to the electrical force acting in between the charges.

Formula

Formula for electrical potential energy stored in a system of two charges:

$$E_E = \frac{kq_Aq_B}{R}$$

Remark. Remember, always input the sign of q_A and q_B

You may notice, there is no negative sign for the formula of electrical potential energy compare to gravitional potential energy.

Gravity is always a force of attraction (this is what causes the negative in the formula)

However, electrical forces can either be forces of attraction or repulsion, which means that electrical energy can either be negative or positive.

$$\text{Repulsion:}+$$
$$\text{Attraction:}-$$

Now we have a new type of mechancial energy to add to our expression!

$$E_M = E_g + E_k + E_s + E_E$$

Remark. Gravitational Potential Energy is typically negligible in compression to electric Potential Energy

1.4.2 Electric Potential for Point Charges

Definition 1.4.2 (Electric Potential)
The electrical Potential per coulomb of charge at a location.

Let's discuss the difference between *electric field* and *electric potential*

Electric Field

- Can exist without there being an electrical force
- To have an electric force, a charge needs to be at a location where there is an electric field
- $\mathcal{E}$
- $\frac{N}{C}$

Electric Potential

- Can exist without there being electrical potential energy
- To have elctric potential energy, a charge needs to be at a location where there is electrical potential
- V
- $\frac{J}{C}$

Formula

Electric Field:

$$\vec{F_E} = \vec{\mathcal{E}} \times q \tag{1.3}$$

Remark. Do <u>not</u> substitue the sign of the charge

Electric Potential:

$$E_E = Vq \tag{1.4}$$

Remark. Substitue the sign of the charge

Calculate the electrical potential around a point charge

$$\begin{aligned} E_E &= Vq_1 \\ \frac{k \times q \times q_1}{R} &= Vq_1 \\ V &= \frac{k \times q}{R} \end{aligned} \tag{1.5}$$

V is the elec potential (of q) at a distance of R away from q

1.5 Electrical Potential Difference

Definition 1.5.1 (Electrical Potential Difference)
The change in the electrical potential between two points, and uses the symbol ΔV

Formula

Assume a charge q goes from a location where the electrical potential is V_1 to a location where the electrical potential is V_2

Electrical Potential Energy of q

Loaction 1:

$E_{E1} = q \times V_1$

Location 2:

$E_{E2} = q \times V_2$

$$\Delta E_E = E_{E2} - E_{E1}$$
$$\Delta E_E = q \times V_2 - q \times V_1$$
$$\Delta E_E = q \times \Delta V \tag{1.6}$$

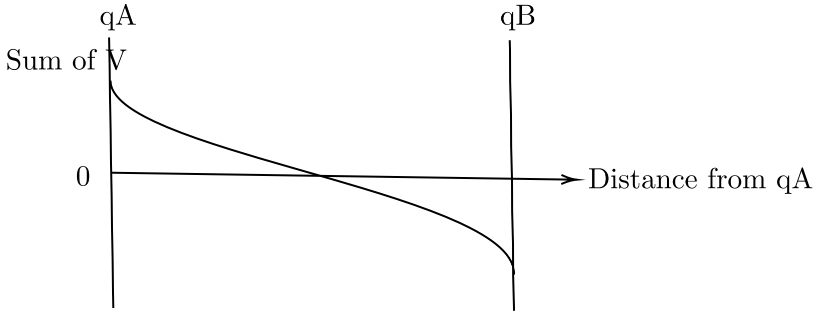
Remark. When use this formula, sub in all the signs!

Theorem 1.5.2
Assume we have two charges, q_A (which is positive) and q_B(which is negative), the total electrical potential at a point in between q_A and q_B will be $V_A + V_B$

If $|q_A| = |q_B|$ and $q_B = -q_A$, the electrical potential at the midpoint in between these two charges is 0.

$$\lim_{position \to q_A} V = \infty$$
$$\lim_{position \to q_B} V = -\infty$$
$$\lim_{position \to midpoint} V = 0$$

A graph of the electrical potential would look like:



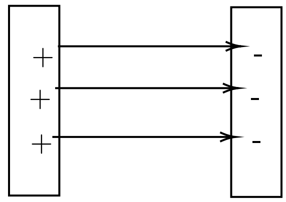
If we put a new charge at the midpoint q_A and q_B, we will find that $V = 0$ and $E_E = 0$. However, the charge would still move. To understand what will happen to this charge, we need to look at the energy gradient

Roll Down!

Remark. About *Energy Gradient*, please follow teacher's note!

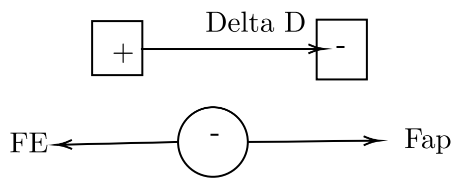
1.6 The electrical field in between two charged parallel plates

The electrical field in between two parallel plates will be uniform



Derive of $\mathcal{E} = \frac{\Delta V}{d}$

Consider a negative charge of q that starts at the positive plate and is pushed at a constant velocity toward the negative plate (by some force)



Lemma 1.6.1
$W_{F_{ap}} = \mathcal{E}qd$

To start of, let's solve for F_{ap}

$$\sum \vec{F} = 0$$
$$F_{ap} - F_E = 0$$
$$F_{ap} = F_E$$
$$F_{ap} = \mathcal{E}q \tag{1.7}$$

Next, let's solve for $W_{F_{ap}}$

$$W_{F_{ap}} = F_{ap} \times \Delta d \times \cos\theta$$

Sub 1.7 in to this equation:

$$W_{F_{ap}} = (\mathcal{E}q) \times 1$$
$$W_{F_{ap}} = \mathcal{E}qd \tag{1.8}$$

The applied force has transferred kinetic energy into q, but q's kinetic energy hasn't changed. The electrical force is doing negative work on q, transferring the kinetic energy that the applied force gave to q into electrical potential energy

Theorem 1.6.2
$\mathcal{E} = \frac{\Delta V}{d}$ *(This is only work for parallel plate question)*

$$\Delta E_E = W_{F_{ap}}$$
$$\Delta E_E = \mathcal{E}qd$$
$$q\Delta V = \mathcal{E}qd$$
$$\Delta V = \mathcal{E}d$$
$$\mathcal{E} = \frac{\Delta V}{d}$$

When we deal with two charged parallel plate, we can say:

$$\Delta E_E = -\Delta E_k$$

When we release the electron, the energy will transfer from Electrical Potential Energy into Kinetic Energy. Kinetic energy increases and Electrical Potential Energy decreases.

We can rearrange this equation:

$$\Delta E_E + \Delta E_k = 0$$