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AIRs - LM in

General Physics 2
Quarter 3: Week 3 - Module 3
Electric Field Vector

General Physics 2
Grade 12 Quarter 3: Week 3 - Module 3: Electric Field Vector
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Target

You have learned in the previous modules about the concepts of electrostatics that contributes to the understanding of electricity. Some notable information about electric field and electric potential of charges. In this module you will discover how charges flow in a capacitor.

After going through this module, you are expected to:

1) ***infer the direction and strength of electric field vector, nature of the electric field sources, and electrostatic potential surfaces given the equipotential lines;***
2) ***calculate the electric field in the region given a mathematical function describing its potential in a region of space;***
3) ***solve problems involving electric potential energy and electric potentials in context such as, but not limited to, electron guns in CRT TV picture tubes and Van de Graff generators;***
4) ***deduce the effects of simple capacitors (e.g., parallel-plate, spherical, cylindrical) on the capacitance, charge, and potential difference when the size, potential difference, or charge is changed; and***
5) ***calculate the equivalent capacitance of a network of capacitors connected in series/parallel.***

Jumpstart

Activity 1: Potential Surface

Objective: Determine the electric potentials at different positions.
Materials: clear plastic tray or glass tray, voltmeter, connecting wires with alligator clips, two aluminum or copper plates, power supply with variable voltage, salt, graphing paper.

Procedure:

1) Place a graphing paper on a table and put the clear plastic or glass tray on top of it.
2) Attach one connecting wire to the positive terminal and another wire to the negative terminal of the power supply. On the free end of each connecting wire, attach the aluminum or copper plate. This will serve as the electrode. The positive electrode is the one attached to the positive terminal of the power supply and the negative electrode is the one attached to the negative terminal.
3) Fill the tray with water about one-fourth full and mix it with salt to produce a salt solution.
4) Immerse the two plates on the solution separately and switch on the power supply. Adjust the voltage to 9.0 V.
5) Tap the positive probe of the voltmeter to the positive electrode and the negative probe to the negative electrode.
6) Immerse the positive probe in the solution near the positive terminal. Move it in the solution to find a voltage reading of 2.0 V. Use the graphing paper to find the coordinates of the 2.0 V potential. Plot the coordinates on a separate sheet of graphing paper. Repeat this step but this time, move to a different location. Take at least five points at which the potential is 2.0 V.
7) Perform another trial, but this time look for the potential readings of 3.0 V and 5.0 V. Plot the coordinates of the pints on the same graphing paper you used earlier. Connect the points by making a smooth curve.

Question:

Describe the locations of the points as the probe moves through the solution. What can you infer based on the result of the activity?

Discover

Capacitance

The energy of a charged particle can be stored in a device known as the *capacitor*. Capacitors have various applications. They can also be found in computers, cell phones, and many other devices. A capacitor serves as a storehouse of energy. It works whenever there is a sudden change in voltage of an electric component. Capacitors are simple passive device that can store an electrical charge on their plates when connected to a voltage source.

Capacitance in a Parallel Plate Capacitor

There are many different kinds of capacitors available from very small capacitor beads used in resonance circuits to large power factor correction capacitors, but they all do the same thing, they store charge.

In its basic form, a capacitor consists of two or more parallel conductive (metal) plates which are not connected or touching each other, but is electrically separated either by air or by some form of a good insulating material such as waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors. The insulating layer between capacitors plates is commonly called the *dielectric*.

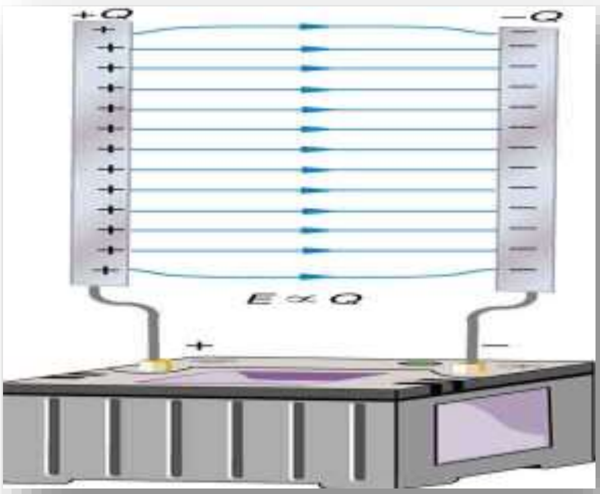

Figure 1. Parallel Plate capacitor

In figure 1, two parallel plates of area A is being stored with charges Q and –Q on opposite plates using a battery of given potential difference. The plates are maintained at a separation distance d. The separation distance is small compared to the area of the plates. The electric filed is almost completely restricted on the area of the plates and the field is uniform. This arrangement is known as a parallel plate capacitor.

> ***Note:***
>
> *Electric field lines in this parallel plate capacitor, as always, start on positive charges and end on negative charges. Since the electric field strength is proportional to the density of field lines, it is also proportional to the amount of charge on the capacitor.*

Capacitance can also be determined using the area A of the plates and the properties of the dielectric material between the plates. Thus, for a parallel plate capacitor, where the capacitance is directly proportional to the area *A* of each conducting plate and inversely proportional to the distance *d* separating the two plates. In mathematical equation it is expressed as:

$$\boxed{C = E_0 \frac{A}{d}}$$

where:

C – capacitance (F)
E_0 – permittivity of the free space that has a value of
<u>8.85×10^{-12} F/m</u>
A - area of the plates (m^2)
D - distance between the plates (m)

During the process of charging, charges are stored on the plates. When voltage is applied to the terminals of the capacitor, electrons move from one plate and flow to the other plate. The total number of electrons in the capacitor remains the same. When charging is complete, the battery can be disconnected. The voltage across the plate is the same as the voltage across the battery.

The capacitor's ability to store electric charge is called capacitance. The stored electric charge *Q* is proportional to the voltage *V* applied to the capacitor of known capacitance *C*. On symbols, this is written as:

$$\boxed{C = \frac{Q}{V}}$$

The SI unit for capacitance is farad *F*. One farad is equivalent to 1 coulomb per volt (C/V). One farad is very large and so prefixes are used to express the smaller units. These other units include 1 microfarad μF which has a value of 10^{-6} F; 1 nanofarad *nF* which has a value of 10^{-9} F; and 1 picofarad *pc* which has a value of 10^{-12} F. When the capacitance is large, the amount of charged stored is greater in a given potential difference.

Cylindrical Capacitor

A special type of parallel plate capacitor in which the insulating dielectric layer is rolled up between the plates. A cylindrical capacitor is made up of a conducting cylinder or wire of radius a surrounded by another concentric cylindrical shell of radius b where b > a. In this type of capacitor a cylindrical conductor having linear charge density $+\lambda$ is surrounded by a coaxial cylindrical conducting shell having charge density $-\lambda$. Due to attraction between unlike charges, the charges will be spread out uniformly on the outer surface of the inner conductor and the inner wall of the outer conductor.

The capacitance of a cylindrical capacitor, depends only on the geometrical factors like length of the cylinder and the radius of the two coaxial cylindrical conductors.

Spherical Capacitor

A spherical capacitor is formed by two concentric conducting spheres. Let's assume that the inner sphere has an outer radius r_1, charge +q and the outer sphere has an inner radius r_2 and charge –q. The electric field is perpendicular to the surface of both spheres and points radially outward. All the capacitors, like batteries, store energy to be used at a later time. But unlike a standard battery, they deliver quick, intense bursts of energy. As a result, capacitors can withstand significantly more charge and discharge cycles than batteries and can deliver more power at a time. Capacitors can even be used with batteries.

Example 1:

1. What is the capacitance of a parallel plate capacitor with metal plates, each of area 1.00 m^2, separated by 1.00 mm?
2. What charge is stored in this capacitor if a voltage of 3.00×10^3 V is applied to it?

Solution:

$$C = 8.85 \text{ x } 10^{-12} \text{ F/m } \frac{1.00 \text{ m2}}{1.00 \text{ x } 10-3}$$

$$C = 8.85\times10^{-9}\ F \quad or \quad 8.85\ nF$$

Capacitors in Series Connection

When the capacitors are placed in a connection where the circuit elements are arranged side by side each other as shown in the figure 2 below, the capacitors are in series connection.

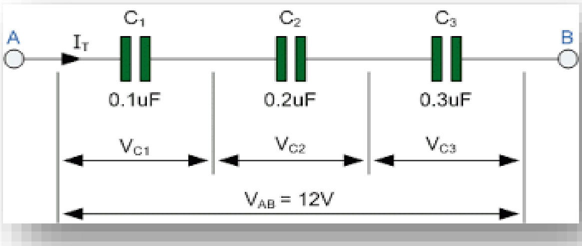

Figure 2. Photo credit: electronic-tutorial

- Capacitors in series all have the same current so each capacitor stores the same amount of charge regardless of its capacitance.

$$Q_T = Q_1 = Q_2 = Q_3 \ldots\ldots$$

- The reciprocal of the equivalent capacitance in a capacitor connected in series is the sum of the reciprocal of the individual capacitance of the capacitors. This means that the equivalent capacitance is always less than the individual capacitance.

$$\frac{1}{CT} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} \ldots\ldots$$

- Since the charge in the equivalent capacitor is the same for both capacitors, then the potential differences across each capacitor can be calculated using:

$$C = \frac{Q}{V} \quad or \quad V = \frac{Q}{C}$$

Example 2:

The capacitors have values C_1 = 7.0 μF and C_2 = 3.0 μF, and the potential difference across the battery is 9.0 V. Assume that the capacitors are connected in series.

a) Find the equivalent capacitance of the circuit.
b) Solve for the potential difference across each capacitors.

Solution for a):

$$\frac{1}{CT} = \frac{1}{7.0\ \mu\text{F}} + \frac{1}{3.0\ \mu\text{F}}$$

$C_{eq} = 2.1\ \mu F$

Solution for b):

$$\boldsymbol{Q = CV} = (2.1\ \mu F)\ (9.0\ V) = \boldsymbol{18.9}\ \mu C$$

$$\boldsymbol{V_1} = \frac{\boldsymbol{Q}}{\boldsymbol{C}} = \frac{18.9\ \mu C}{7.0\ \mu F} = \boldsymbol{2.7\ V}$$

$$\boldsymbol{V_2} = \frac{\boldsymbol{Q}}{\boldsymbol{C}} = \frac{18.9\ \mu C}{3.0\ \mu F} = \boldsymbol{6.3\ V}$$

The equivalent capacitance found in part a is less than the value of the capacitance in the capacitor. In part b, the largest value of potential difference was obtained for the smallest value of capacitance. Notice also that the sum of the potential differences across the 7.0 microfarad and the 3.0 microfarad capacitors would be 9.0 V, which is the potential difference across the battery.

Capacitors in Parallel Connection

When capacitors are placed in circuit connection as shown in figure 3, the capacitors are in parallel connection.

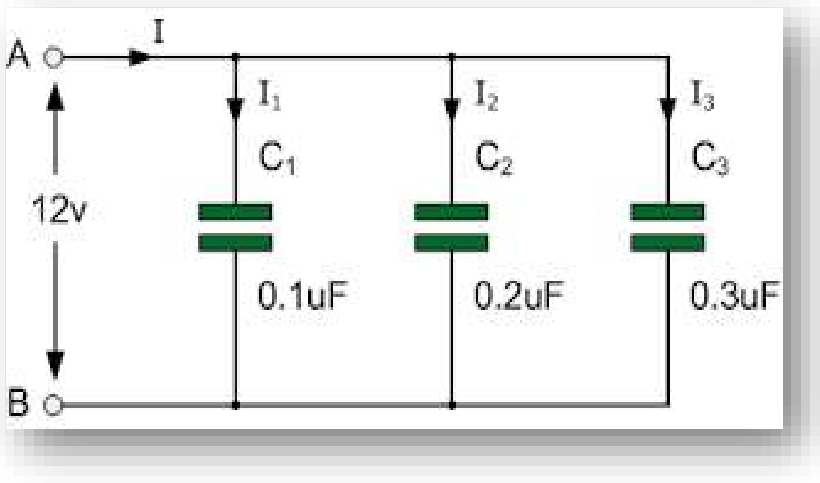

Figure 3. Photo credit: electronic-tutorial

- The equivalent capacitance for capacitors connected in parallel is the sum of the individual capacitance of the capacitors. This means that the equivalent capacitance is greater than the individual capacitance.

$$C_{eq} = C_1 + C_2 + C_3.....$$

- In a parallel connection, the potential difference across each capacitor is the same as the potential difference across the battery.
- The charge on each capacitor can be calculate using:

$$C = \frac{Q}{V} \quad or \quad Q = CV$$

Example 3:

The capacitors have values C_1 = 7.0 μF and C_2 = 3.0 μF, and the potential difference across the battery is 9.0 V. Assume that the capacitors are connected in parallel.

a) Find the equivalent capacitance of the circuit.
b) Solve for the charge across each capacitors.

Solution for a):

$$C_{eq} = 7.0\ \mu F + 3.0\ \mu F$$

$$= 10.0\ \mu F$$

Solution for b):

$Q_1 = CV = (7.0\ \mu F)(9.0\ V)$

$\mathbf{Q_1 = 63\ \mu C}$

$Q_2 = CV = (3.0\ \mu F)(9.0\ V)$

$\mathbf{Q_1 = 27\ \mu C}$

The equivalent capacitance is larger than the value of the individual capacitor as in part a. In part b, the capacitor with the largest value has the largest amount of charge. Getting the sum of the charges for both capacitors gives the total charge for the equivalent capacitance.

Explore

Activity 2: Practice Problems

Direction: Solve the problems systematically. *(10 points each).*

1. What is the capacitance of a parallel plate capacitor with metal plates, each of area 1.00 m^2, separated by 2.00 mm? What charge is stored in this capacitor if a voltage of 3.00×10^3 V is applied to it?

2. The capacitors have values $C_1 = 2.0\ \mu F$ and $C_2 = 4.0\ \mu F$, $C_3 = 5.0\ \mu F$ $C_4 = 7.0\ \mu F$ and the potential difference across the battery is 9.0 V. Assume that the capacitors are connected in series.
   a) Find the equivalent capacitance of the circuit.
   b) Solve for the potential difference across each capacitors.

3. Given the same problem in #2. Assume that the capacitors are connected in parallel.
   a) Find the equivalent capacitance of the circuit.
   b) Solve for the charge across each capacitors.

Deepen

Activity 3: Performance Tasks

A. You are an engineer in a company that makes capacitors. You will make an improvised capacitor that uses aluminum, paper, and any other readily available materials. Make sure that your capacitor can be used when charged. Include in your product some information such as how long it can supply energy. Your product should function properly, be made of locally available materials, and conform to concepts related to capacitors.

B. You are a creative designer of a nongovernmental organization. You have been tasked to create a photo essay with this theme: “When charges went wrong: Describing the effects of the irregularities of charges.” Include in the photo essay your ideas on the theme and how you can present it creatively to create public awareness about the effects of charges. Your photo essay should conform to the theme, and it should be unique and artistically designed.

C. Devise or create an activity about capacitor. Include the following to your report: objective, material, procedure, questions, and conclusion.

Note: The teacher will provide his/ her own rubric of every performance task.

Gauge

Directions: Read carefully each item. Write only the letter of the best answer. Use a separate sheet of paper for your answers.

A. Multiple Choices Test (5 points)

______1. What is the insulating material that is placed in between capacitors to maintain the smallest possible separation between the plates?

A. dielectric B. diatomic C. diode D. drape

______2. What is the storehouse of energy for electrical devices?

A. capacitance B. capacitor C. battery D. resistor

______3. Which of the following statements is TRUE?

A. The SI unit for capacitance is farad
B. Farad is equivalent to joule per second
C. Capacitance is the ratio between charge and resistor
D. Capacitance increases when capacitors are connected in a series

______4. Which of the following statements is TRUE about capacitors?

A. In series connection, voltage is the same.
B. In series connection, all have the same amount of charge
C. In parallel, the equivalent resistance decreases
D. In series, the equivalent resistance increases

______5. What is the SI unit for capacitance?

A. force B. resistance C. ohms D. farad

B. Problem Solving (10 points)

6-10. What is the capacitance of a parallel plate capacitor with metal plates, each of area 1.50 m^2, separated by 2.01 mm? What charge is stored in this capacitor if a voltage of 2.50×10^3 V is applied to it?

11-15. The capacitors have values C_1 = 2.5 μF and C_2 = 4.0 μF, C_3 = 6.0 μF C_4 = 8.0 μF and the potential difference across the battery is 12.0 V. Assume that the capacitors are connected in series. Find the equivalent capacitance of the circuit and solve for the potential difference across each capacitors.

Answer Key

JUMPSTART

Activity 1: The simple activity illustrates what is called equipotential surface. An Equipotential surface is where electric potential is the same at every point. This is an analogy of contour lines seen in a topographic map.

EXPLORE

Activity 2:
1) 4.425×10^{-9} F or 4.425 nF
2) 0.92 μF
3) 18 μF

DEEPEN

Activity 3: Answers may vary

GAUGE:

1. A 2. A 3. A 4. B 5. D

6-10) 6.60×10^{-9} F or 6.60 nF

11-15) 1.06 μF

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