Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

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Chapter 2: Electrostatic Potential And Capacitance

Chapter 2: Electrostatic Potential And Capacitance

Introduction

In the previous chapter, we have learnt about "Electric Charges and Fields". In this chapter, we shall focus Electrostatic Potential and Capacitance. The energy point of view can be used in electricity, and it is especially useful. Energy is also a tool in solving Problems more easily in many cases then by using forces and electric fields.

Electric energy can be stored in a common device called a capacitor, which is found in nearly all electronic circuits. A capacitor is used as a storehouse for energy. Capacitors store the energy in common photo flash units.

Chapter 2: Electrostatic Potential And Capacitance

Electrostatic Potential:

The electrostatic potential (V) at any point in a region with electrostatic field is the work done in

bringing a unit positive charge (without acceleration) from infinity to that point. If 'W' is the work

done in moving a charge ‘q’ from infinity to a point, then the potential at that point is

$$V = \frac{W}{q}$$

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Electrostatic Potential:

Electric Potential Difference:

Similar to electric potential, the electric potential difference is the work done by external force in

bringing a unit positive charge from point R to point P. i.e.,

$$V_P - V_R = \frac{U_P - U_R}{q}$$

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Electrostatic Potential:

Here VP and VR are the electrostatic potentials at P and R, respectively and UP and UR are the potential energies of a charge q when it is at P and at R respectively.

Note: As before, that it is not the actual value of potential but the potential difference that is physically significant. If, as before, we choose the potential to be zero at infinity, the above equation implies.

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Electrostatic Potential:

Unit for Electric Potential:

The unit of measurement for electric potential is the volt, so electric potential is often called voltage. A potential of 1 volt (V) equals 1 joule (J) of energy per 1 coulomb (C) of charge.

$$1V = 1\ \frac{J}{c}$$

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Conservative Forces:

When one form of energy gets converted to another completely on application or removal of external force, the forces are said to be conservative. Examples of conservative forces are sum of kinetic and potential energies working on a body, spring and gravitational force, coulomb force between two stationary charges, etc.

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Conservative Forces:

Work done in moving an object from one point to another depends only on the initial and final positions and is independent of the path taken.

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Potential due to a Point Charge:

Consider a point charge q placed at point O. Consider any point P in the field of the above charge. Let us calculate the potential at point P due to the charge q kept a point O. Since work done is independent of path, we choose a convenient path, along the radial direction.

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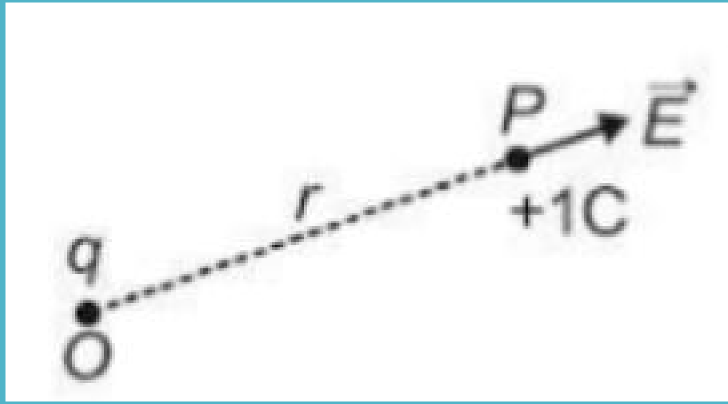
Potential due to a Point Charge:



Let the distance OP = r.

The electric force at P, due to q will be directed along OP, given by

$$F = \frac{1}{4\pi\varepsilon_0} = \frac{qq_0}{r^2}$$

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Potential due to a Point Charge:

If the work done by moving this positive charge to dr distance is dW then,

$$dW = F\,(-dr)$$

$$dW = -\int F.dr$$

$$dW = -\int_{\infty}^{r} F.dr$$

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Potential due to a Point Charge:

Hence, the total work done in bringing this charge from (∞) to 'r' will be,

$$W = \int_{\infty}^{r} \frac{1}{4\pi\varepsilon_0} \frac{qq_0}{r^2} . dr$$

$$W = -\frac{qq_0}{4\pi\varepsilon_0} \int_{\infty}^{r} \frac{1}{r^2} . dr$$

$$W = -\frac{qq_0}{4\pi\varepsilon_0} \left[-\frac{1}{r} \right]_{\infty}^{r}$$

$$W = \frac{1}{4\pi\varepsilon_0} \frac{qq_0}{r^2}$$

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Potential due to a Point Charge:

Hence, from $V = \frac{W}{q_0}$ electric potential is,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

This equation is true for any sign of charge q. For $q < 0$, $V < 0$, i.e., work done by the external force per unit positive test charge to bring it form infinity to the point is negative. Also, this equation is consistent with the choice that potential at infinity be zero.

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Equipotential Surfaces:

An equipotential surface is a surface with a constant value of potential at all points on the surface. For a single charge q, the potential is given by

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

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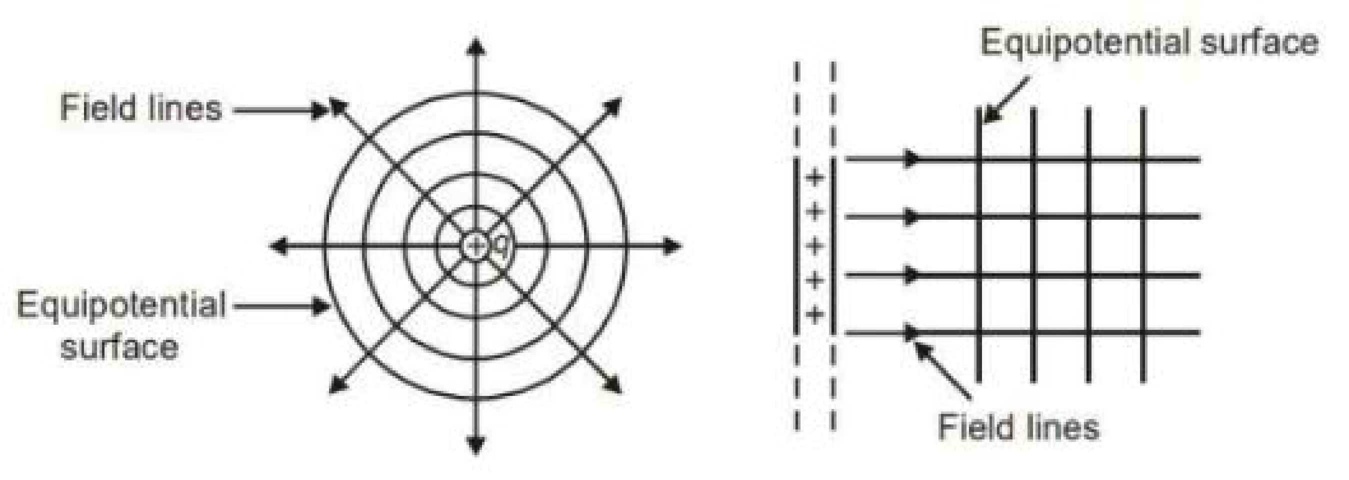
Equipotential Surfaces:

This shows that V is a constant if r is constant. Thus, equipotential surfaces of a single point charge are concentric spherical surfaces centered at the charge.



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Equipotential Surfaces:

Example:

- Surface of a charged conductor.
- All points equidistant from a point charge.

Note:

- An equipotential surface is that at which, every point is at the same potential. As the work done is given by $(V_A - V_B)q_0$.
- Work done by electric field while a charge moves on an equipotential surface is zero as $V_A = V_B$.

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Electrostatics of Conductors:

Conductors contain mobile charge carriers. In metallic conductors, these charge carriers are electrons. In a metal, the outer (valence) electrons part away from their atoms and are free to move. These electrons are free within the metal but not free to leave the metal.

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Electrostatics of Conductors:

Whenever a conductor is placed in an external electric field, the free electrons in it experience a force due to it and start moving opposite to the field. This movement makes one side of conductor positively charged and the other as negatively charged. This creates an electric field in

the conductor in a direction opposite to external electric field (called induced field).

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Important Points about Electrostatics of Conductors:

Inside a conductor, electrostatic field is zero:

In the previous chapter, we have already discussed that "when there is no electric current inside or on the surface of a conductor, the electric field inside the conductor is everywhere zero".

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Important Points about Electrostatics of Conductors:

At the surface of a charged conductor, electrostatic field must be normal to the surface at every point:

If the field E is not normal to the surface, it will have a nonzero component along the surface. Hence the free charge on the surface will move due to electrostatic force on it. But free charge on the surface in electrostatics remains at rest. So, the electrostatic field at the surface of a charged conductor must be normal to the surface.

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Important Points about Electrostatics of Conductors:

Electrostatic Shielding:

In an electrostatic situation, if a conductor contains a cavity and if nom charge is present inside the cavity, then there can be no net charge anywhere on the surface of the cavity. This means that if you are inside a charged conducting box, you can safely touch any point on the inside walls of the box without being electrocuted. This is known as electrostatic shielding.

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Dielectrics and Polarization:

Dielectrics are non-conducting substances. In contrast to conductors, they have no (or negligible number of) charge carriers. When a conductor is placed in an external electric field, the free charge carriers move and charge distribution in the conductor adjusts itself in such a way that the electric field due to induced charges opposes the external field within the conductor. This happens until, in the static situation, the two fields cancel each other and the net electrostatic field in the conductor is zero.

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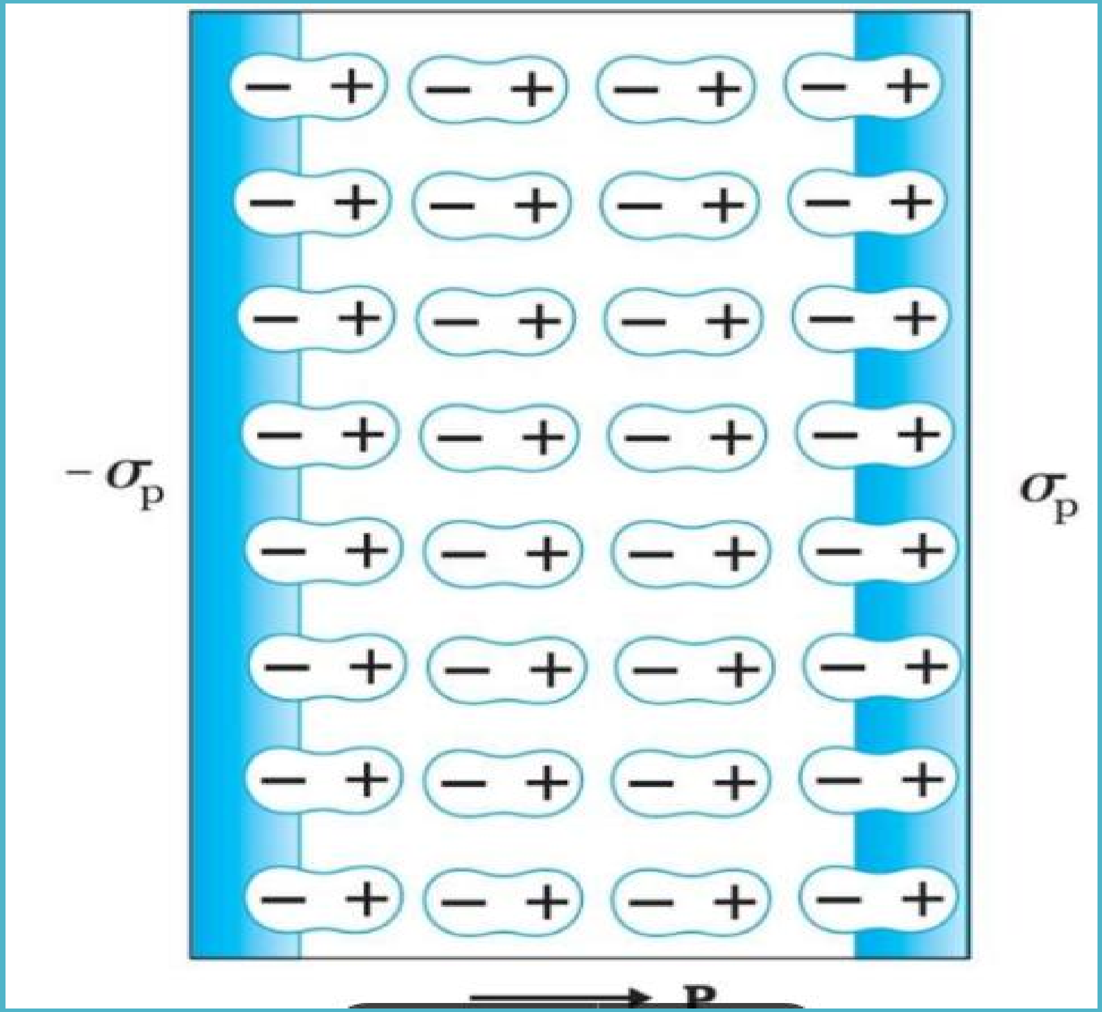
Dielectrics and Polarization:



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Dielectrics and Polarization:

When a dielectric material is kept in an electric field, the external field induces dipole moment by stretching or reorienting molecules of the dielectric. This results in development of net charges on the surface of the dielectric which produce a field that opposes the external field.

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Dielectrics and Polarization:

In general, the dielectric can be classified into Polar and Non-polar dielectrics. In a non-polar molecule, the centers of positive and negative charges coincide. The molecule thus has no permanent dipole moment. Examples of non-polar molecules are oxygen (O_2) and hydrogen (H_2) molecules which, because of their symmetry, have no dipole moment. On the other hand, a polar molecule is one in which the centers of positive and negative charges are separated (even when there is no external field). Such molecules have a permanent dipole moment. An ionic molecule such as HCl or a molecule of water (H_2O) are examples of polar molecules.

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Dielectrics and Polarization:

Behavior of a non–polar dielectric: In an external electric field, the positive and negative charges of a nonpolar molecule are displaced in opposite directions. The displacement stops when the external force on the constituent charges of the molecule is balanced by the restoring force. The non-polar molecule thus develops an induced dipole moment. The dielectric is said to be polarized by the external field.

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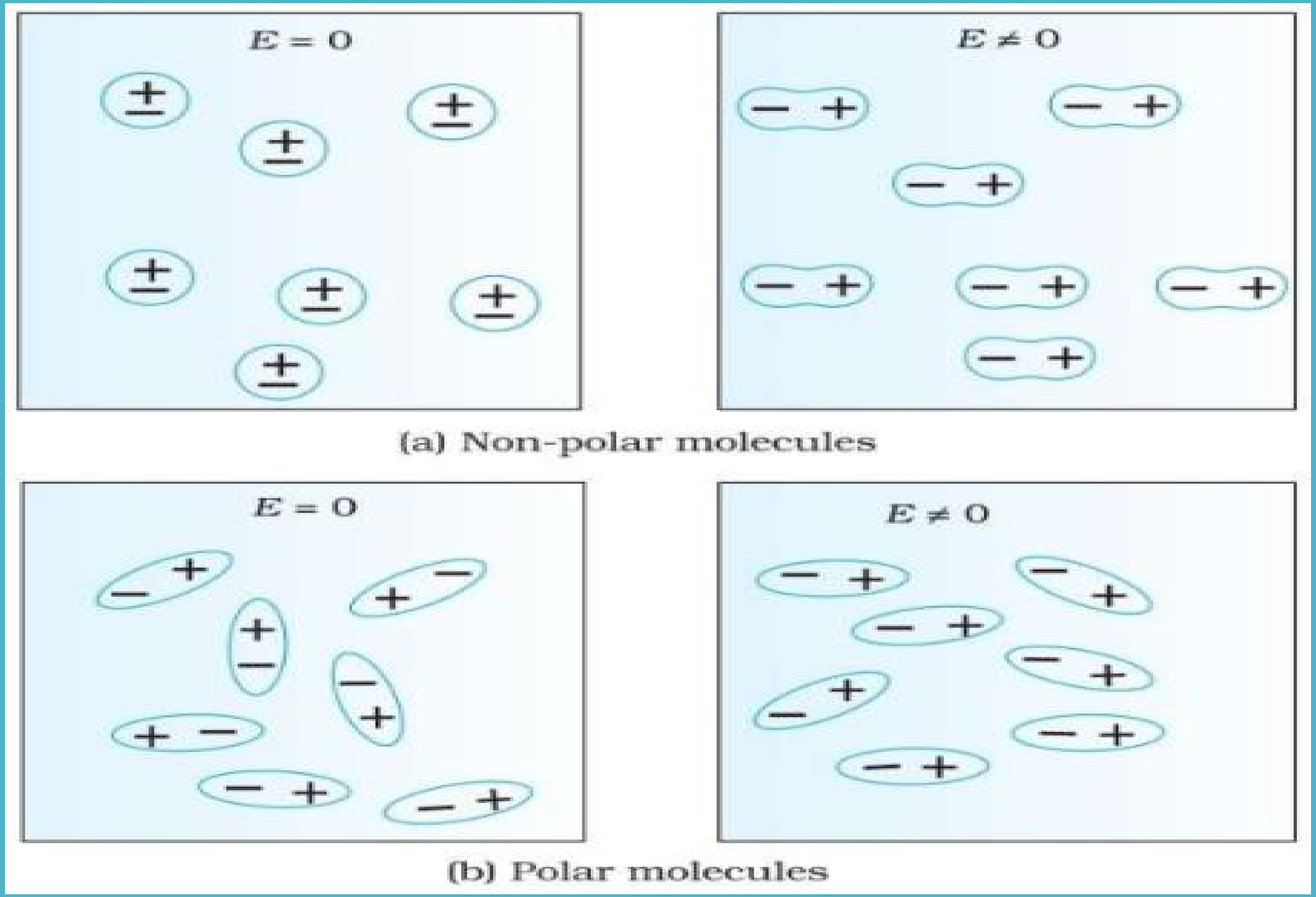
Dielectrics and Polarization:



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Dielectrics and Polarization:

Behavior of a polar dielectric:

A dielectric with polar molecules also develops a net dipole moment in an external field, but for a different reason. In the absence of any external field, the different permanent dipoles are oriented randomly due to thermal agitation; so, the total dipole moment is zero. When an external field is applied, the individual dipole moments tend to align with the field.

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Capacitors and Capacitance:Dielectrics and Polarization:

A capacitor is a system of two conductors separated by an insulator. If two conductors have a potential difference between them then, as any potential difference is able to accelerate charges, the system effectively stores energy. Such a device that can maintain a potential difference, storing energy by storing charge is called capacitor. When charges +Q and –Q are given to two plates, a potential difference is developed between the plates. The capacitance of the arrangement is defined as.

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

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Capacitors and Capacitance:Dielectrics and Polarization:

Definition of Capacitance:

Capacitance is defined as the amount of charge required to raise the potential of a conductor by one volt.

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Capacitors and Capacitance:Dielectrics and Polarization:

Capacity of an isolated spherical conductor:

Consider a sphere with center O and radius r, which is supplied with a charge = +q. This charge is distributed uniformly over the outer surface of the sphere. Thus, the potential at every point on the surface is same and is given by.

$$V = \frac{q}{4\pi\varepsilon_0 r}$$

$$\text{As } C = \frac{Q}{V}$$

$$C = 4\pi\varepsilon_0 r$$

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Capacitors and Capacitance:Dielectrics and Polarization:

The Parallel Plate Capacitor:

The arrangement consists of two thin conducting plates, each of area A and separated by a small distance d. When charge q is given to first plate, a charge –q is induced on the inner face of other plate and positive on the outer face of plate. As this face is connected to earth, a net negative

charge is left on this plate. Thus, the arrangement is equivalent to two thin sheets of charge. As d is much smaller than the linear dimension of the plates (d2<< A), we can use the result of electric field by an infinite sheet of charge. The electric field between the plates is.

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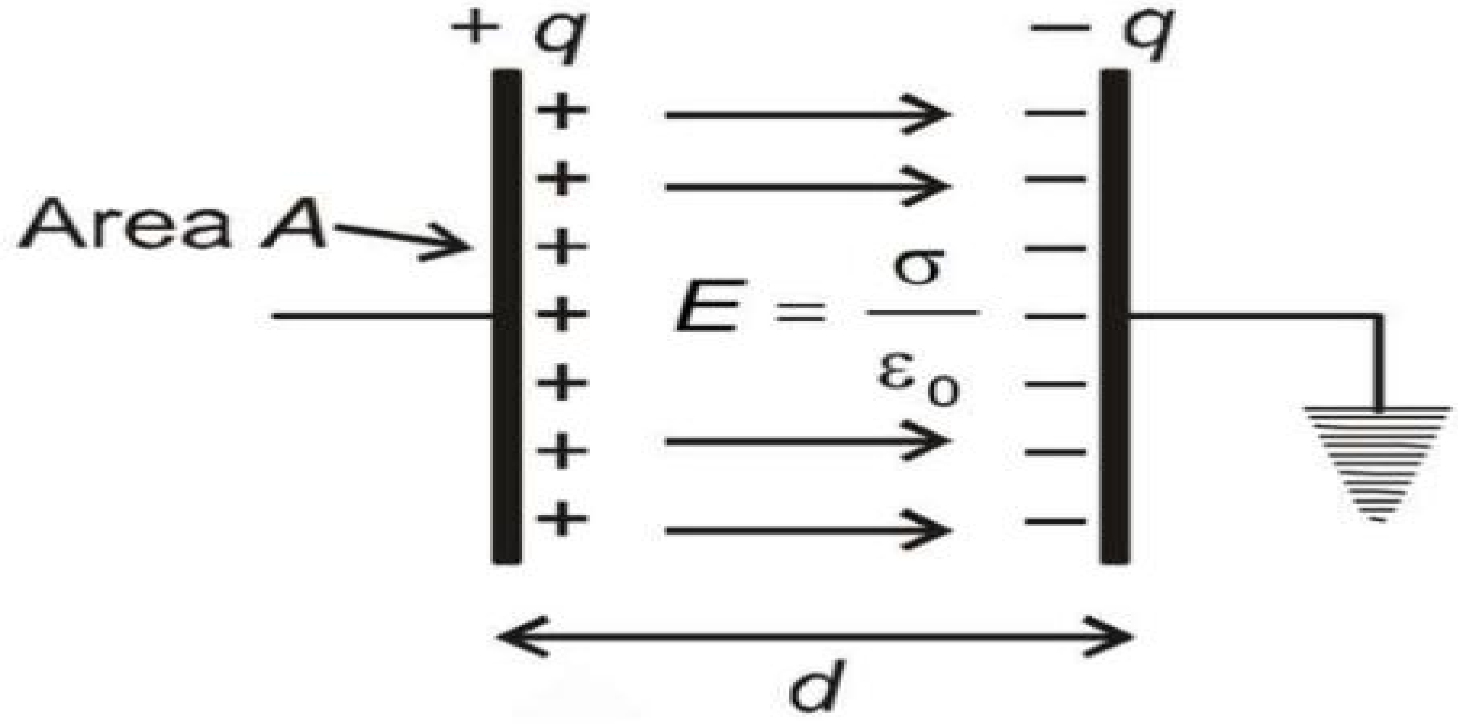
Capacitors and Capacitance:Dielectrics and Polarization:



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

$$E = \frac{\sigma}{\varepsilon_0} \ldots.(1)$$

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Capacitors and Capacitance:Dielectrics and Polarization:

For uniform field potential difference between the plates.

$$V = Ed = \frac{\sigma d}{\varepsilon_0} \ldots\text{. From eq (1)}$$

$$V = \frac{qd}{\varepsilon_0 A} \text{ as } \sigma = \frac{q}{A}$$

$$C = \frac{q}{V} = \frac{q}{\frac{qd}{\varepsilon_0 A}}$$

$$C = \frac{\varepsilon_0 A}{d}$$

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Capacitors and Capacitance:Dielectrics and Polarization:

Effect of Dielectric on Capacitance:

When a dielectric slab of dielectric constant K is inserted between the plates filling the entire space between the plates. The plates of the capacitor are given charge +Q and –Q and hence induced charges –QP and +QP appear on the surfaces of the slab. So, capacitance is increased to K times when the space between the plates is filled with a dielectric of dielectric constant K.

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Combination of Capacitors:

Series Grouping:

The arrangements shown in figure are examples of series grouping. When capacitors can be arranged in a row, so that there is no connection from in between two capacitors to any third capacitor, it is called a series combination. Or, when same charge flows through each capacitor connected.

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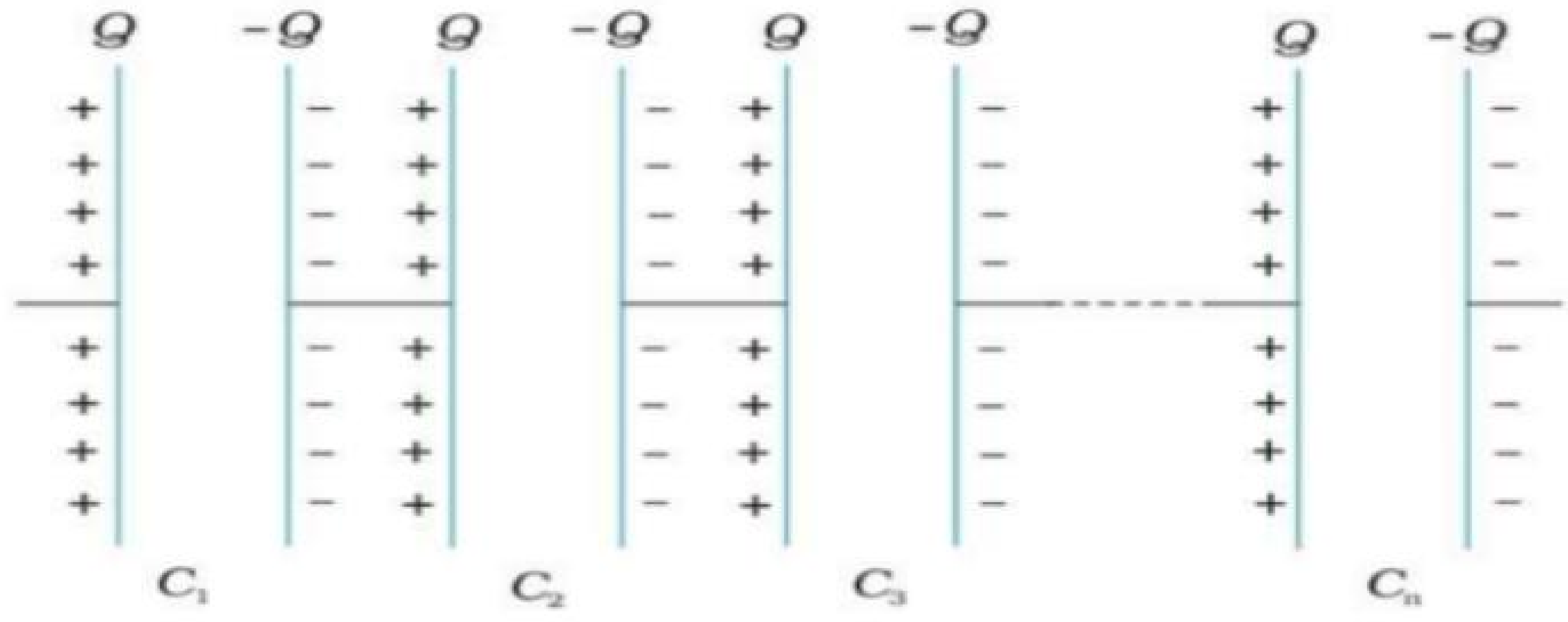
Combination of Capacitors: Series Grouping:



$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

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Combination of Capacitors:

Parallel Grouping:

The arrangements shown in figure are examples of parallel combination. When two or more capacitors are connected between two given points, they are said to be in

parallel. Or, when capacitor bears same potential difference across it.

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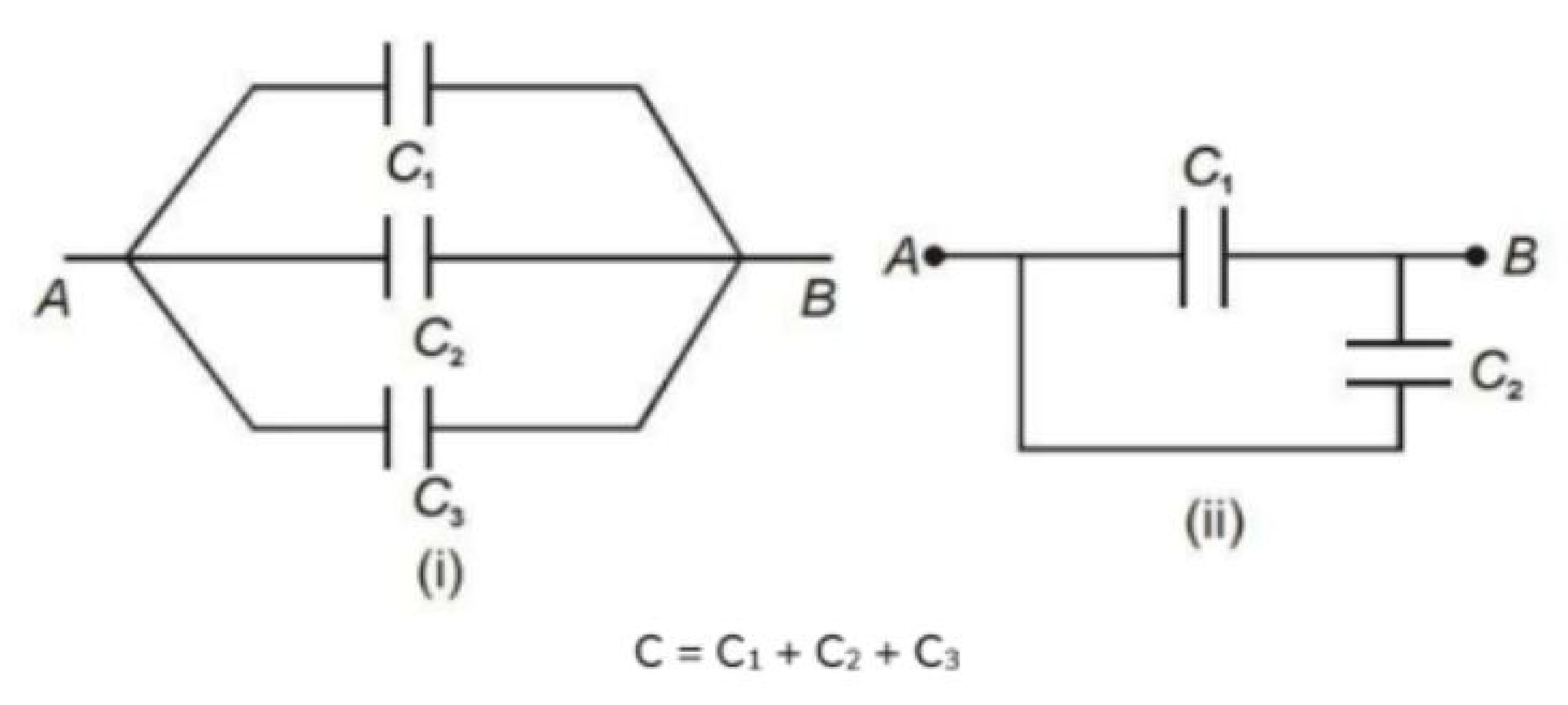
Combination of Capacitors: Parallel Grouping:



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Van de Graaff Generator:

Van de Graaff generator is a machine that can built up voltages in order of a few million volts.

The resultant electric fields are used to accelerate charged particles (proton, electrons, ions) to high energies required for experiments to examine small scale structure of matter.

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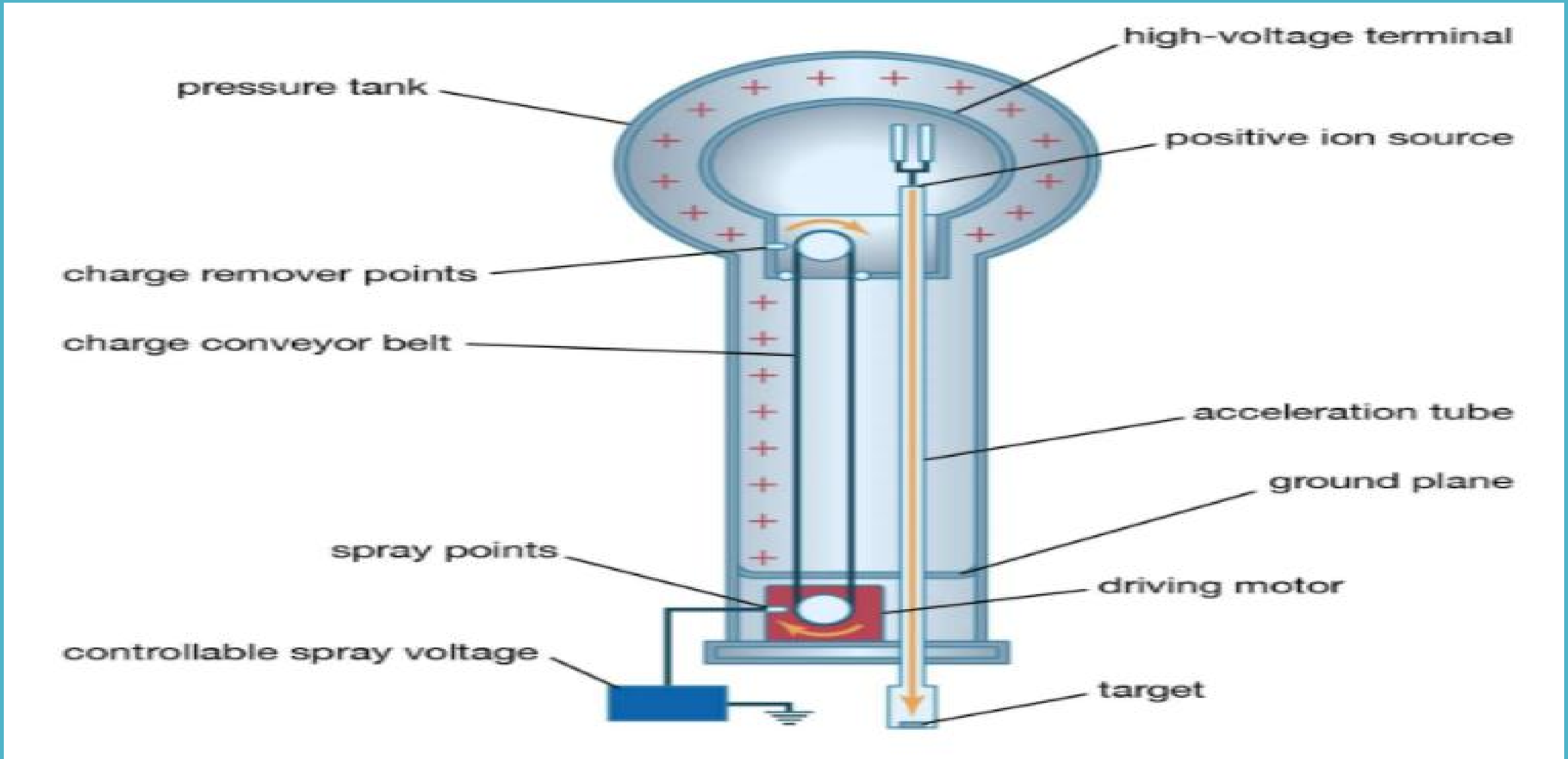
Van de Graaff Generator:



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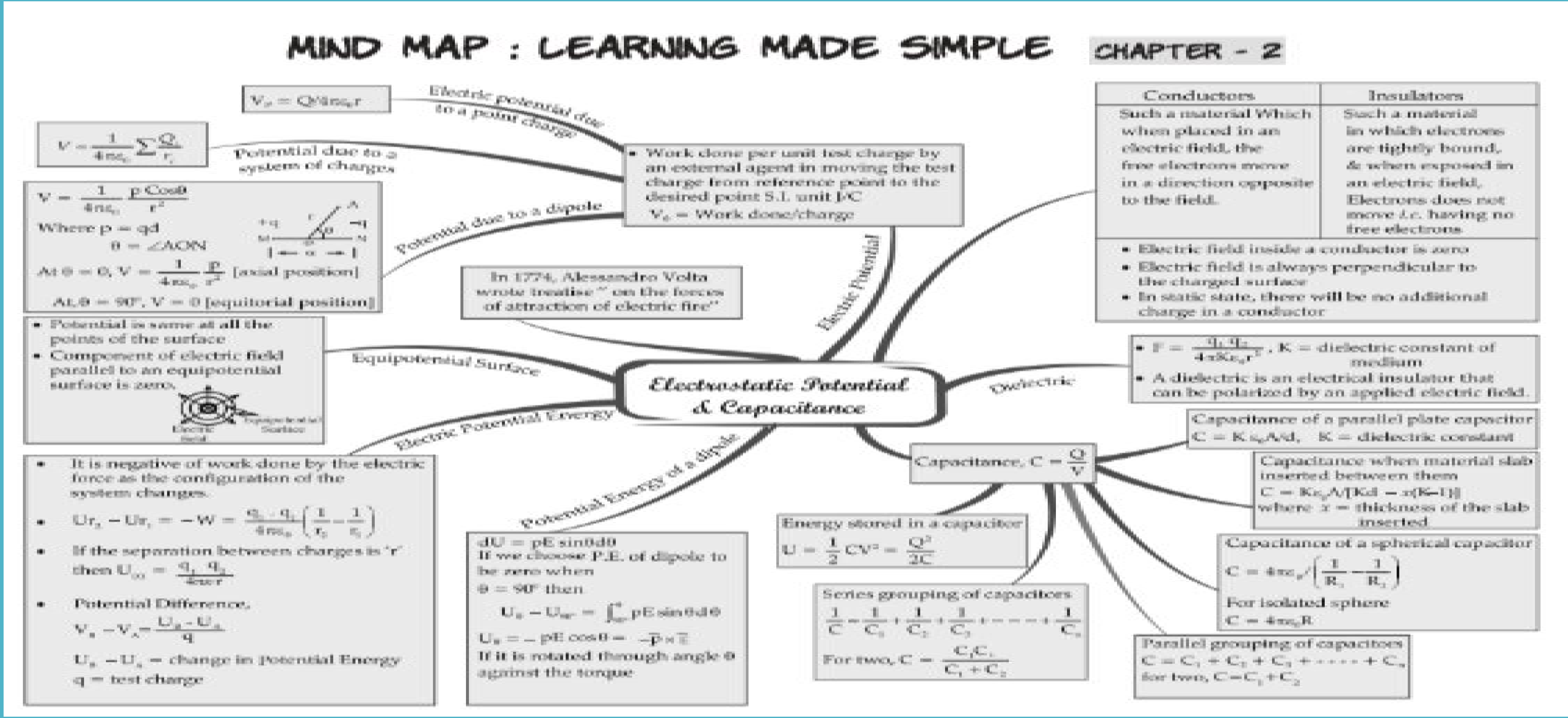

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