



4

ELECTRIC FIELD

Matter consists of electrically charged particles. These particles exert electrical forces of attraction or repulsion on themselves. The space around charged particles where electric force can be exerted on other charged particles is called **electric field**.

OBJECTIVES

At the end of this topic, students should be able to:

- state Coulomb's law and calculate the electric force between two charges;
- explain electric field, electric field intensity and electric potential.
- solve problems on Coulomb's law, electric field intensity and electric potentials.

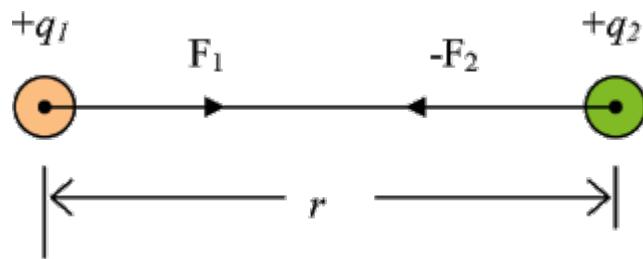
Electric force between point charges

In 1875, Coulomb showed that two charged particles will attract or repel each other with a force which is:

- directly proportional to product of the magnitude of their charges; ($F \propto q_1 q_2$).....i
- inversely proportional to the square of the distance between (r) separating their centres.

$$F \propto \frac{1}{r^2} \quad \dots\dots\dots ii$$

The electric force is an inverse square law force; that is, electric force decreases very fast as the charges move away from each other. When the expressions above are combined, we obtain;



$$F \propto \frac{q_1 q_2}{r^2} \dots\dots iii$$

Coulomb's law

The force of attraction or repulsion between two electric charges q_1 and q_2 is proportional to the product of the charges and inversely proportional to the square of the distance between them.

Removing the proportionality sign and adding a constant on the right hand side of *iii* gives;

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

The constant $\hat{\epsilon}_0$ is called **electrostatic constant**. The magnitude of $K = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$.

The constant $\hat{\mu}_0$ is called the **permittivity of air (free space)**. Materials with high permittivity allow electric field to pass through them. Materials like insulators, which can separate positive and negative charges, will permit electric field to pass through them. Substituting the value of $\hat{\epsilon}_0$ gives:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

Two like charges repel (push away from each other) while unlike charges attract (move towards each other). Figure 4.1 shows three charges arranged in a triangle.

The forces acting on the charges are as shown in Figure 4.1, the charge q_2 is attracted by the charge q_3 in the direction of the force $F_{2,3}$ and repelled by charge q_1 in the direction of the force $F_{2,1}$. The resultant of forces $F_{2,3}$ and $F_{2,1}$ is F_2 , therefore, the charge q_2 moves in the direction of the force F_2 . The force F_1 is the resultant of $F_{1,2}$ and F_1 .

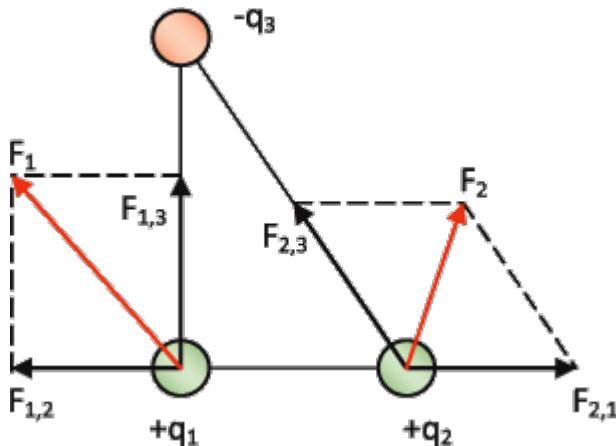


Figure 4.1: Electrical forces between charges

Worked examples

An electron with charge $-1.6 \times 10^{-19} \text{ C}$ orbits a proton with charge $1.6 \times 10^{-19} \text{ C}$ at a distance of $5.9 \times 10^{-11} \text{ m}$, calculate the electrostatic force of attraction between the electron and the proton.

{Electrostatic constant $k = 9.0 \times 10^9 \text{ Nm}^2\text{C}^{-2}$ }

Solution

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$F = \frac{9.0 \times 10^9 \times (-1.6 \times 10^{-19})(1.6 \times 10^{-19})}{(5.9 \times 10^{-11})^2}$$

$$F = -6.62 \times 10^{-8} \text{ N.}$$

2. Find the force of repulsion between two positive charges of magnitudes $3.0 \times 10^{-6} \text{ C}$ and $2.0 \times 10^{-6} \text{ C}$ if they are 1 cm apart. {Electrostatic constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{C}^{-2}$ }

Solution

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \quad F = \frac{9.0 \times 10^9 \times (3.0 \times 10^{-6})(2.0 \times 10^{-6})}{(1.0 \times 10^{-2})^2}$$

$$F = 54 \text{ N.}$$

Electric field

Electric field is the region or space around a charge where electric force can be exerted on another charge.

Electric field line

An electric field line is the path traced by a small positive test charge as it moves in an electric field.

Electric field line is also called electric line of force or electric line of flux. The electric field around any charged body is made up of many lines of force.

Electric field intensity (strength)

Electric field intensity or strength is the force acting on a unit positive charge in an electric field.

$$\text{Electric field intensity} = \frac{\text{Force}}{\text{Charge}}$$

$$W = \frac{1}{2} QV = \frac{100}{0.01} = 10,000 \text{ Vm}^{-1}$$

$$\text{Capacitance} = \frac{\text{Charge stored}}{\text{Voltage}}$$

$$E = \frac{F}{q} \quad \text{or} \quad F = qE$$

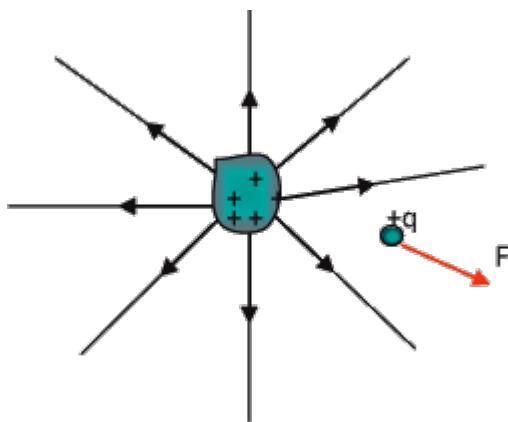


Figure 4.2: The strength of an electric field is the force (F) it exerts on a unit positive charge $+q$

The unit of electric field intensity (E) is Newton per coulomb (NC^{-1}) or volt per metre (Vm^{-1}). It is a vector, having both direction and magnitude.

The intensity of an electric field is measured by the magnitude of the force it exerts on a charge placed in it. Where the electric field intensity is high, the electric field lines are closer to each other.

The magnitude of electric field intensity (E)

The magnitude of electric field intensity (E) at any point in the electric field depends on the nature of the charge, the size of the charge and the distance of the point from the charge.

(a) Nature of the charge: The magnitude of the electric field intensity at a point P

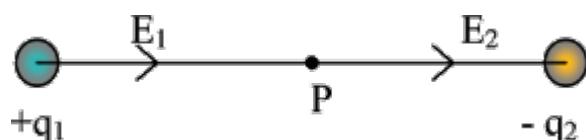
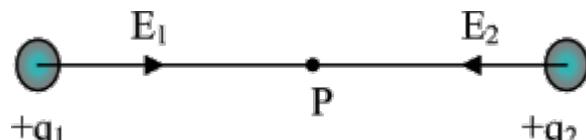
depends on the nature of the charges q_1 and q_2 .

(i) point P between two like charges;

The resultant electric field intensity E at the point P is given by $E = E_2 - E_1$ ($E_2 > E_1$)

(ii) point P between two unlike charges;

The resultant electric field intensity E at the point P is given by $E = E_2 + E_1$.



(b) Size of the charges: The electric field intensity is strong for large charges and weak for small charges. A charge of $6.0 \text{ Å} - 10^{-6} \text{ C}$ will produce a stronger field than a charge of $1.0 \text{ Å} - 10^{-6} \text{ C}$ at the same distance from the charge.

(c) Distance of the charges from the point: Electric field intensity (E) obeys an inverse square law; therefore, the closer the point is to the charge, the stronger the electric field intensity.

The electric field intensity (E) varies with the distance of the point r from the source of the field as follows:

The force acting on the charge q placed at a distance r from the source of the field Q is given by coulomb's law as

$$E = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2} \dots\dots\dots i$$

$$F = qE \dots\dots\dots ii$$

Also

Equating the two forces in *i* and *ii* gives

$$E = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$$

Worked examples

1. An electron of charge $-1.6 \text{ Å} - 10^{-19} \text{ C}$ experiences a constant force of magnitude $3.2 \text{ Å} - 10^{-7} \text{ N}$. Calculate:

- (a) the electric field intensity exerting this force on the electron;
 - (b) how far the electron is from the source of the field.
- {Electrostatic constant $k = 9.0 \text{ Å} - 10^9 \text{ N m}^2 \text{ C}^{-2}$ }

Solution

$$(a) \text{ Electric field intensity} = \frac{\text{Force}}{\text{Charge}} \quad E = \frac{3.2 \times 10^{-7}}{1.6 \times 10^{-19}} = 2.0 \times 10^{12} \text{ NC}^{-1}$$

$$(b) r^2 = \frac{1}{4\pi\epsilon_0} \frac{Q}{E} = \frac{9.0 \times 10^9 \times 1.6 \times 10^{-19}}{2.0 \times 10^{12}}$$

$$r^2 = 7.2 \times 10^{-22}$$

$$r = 2.68 \times 10^{-11} \text{ m}$$

2. What is the magnitude of the electric field intensity at a point 3.0 cm from a charge of magnitude $2.7 \text{ Å} - 10^{-6} \text{ C}$?

{Electrostatic constant $k = 9.0 \text{ N m}^2 \text{ C}^{-2}$ }

Solution

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} = \frac{9.0 \times 10^9 \times 2.7 \times 10^{-6}}{(3.0 \times 10^{-2})^2} \quad E = 2.7 \times 10^7 \text{ N C}^{-1}$$

3.Two charges of magnitudes 2.0 C and 3.0 C are 7 cm apart. Find the resultant electric field at a point:

(a)P, between the charges and 3.0 cm from the bigger charge.

(b)R, outside the charges and 2.0 cm from the smaller charge. {Electrostatic constant $k = 9.0 \text{ N m}^2 \text{ C}^{-2}$ }

Solution

$$(a) \quad E_1 = \frac{1}{4\pi\epsilon_0} \frac{Q_1}{r_1^2} = \frac{9.0 \times 10^9 \times 2.0 \times 10^{-6}}{(4.0 \times 10^{-2})^2}$$

$$E_1 = 1.125 \times 10^7 \text{ N C}^{-1}.$$

$$E_2 = \frac{1}{4\pi\epsilon_0} \frac{Q_2}{r_{21}^2} = \frac{9.0 \times 10^9 \times 3.0 \times 10^{-6}}{(3.0 \times 10^{-2})^2}$$

$$E_2 = 3.0 \times 10^7 \text{ N C}^{-1}.$$

Resultant electric field $E = E_2 - E_1$

$$E = 3.0 \times 10^7 \text{ N C}^{-1} - 1.125 \times 10^7 \text{ N C}^{-1}.$$

$$E = 1.875 \times 10^7 \text{ N C}^{-1}.$$

$$(b) \quad E_2 = \frac{1}{4\pi\epsilon_0} \frac{Q_2}{r_{21}^2} = \frac{9.0 \times 10^9 \times 2.0 \times 10^{-6}}{(2.0 \times 10^{-2})^2}$$

$$E_2 = 4.50 \times 10^7 \text{ N C}^{-1}.$$

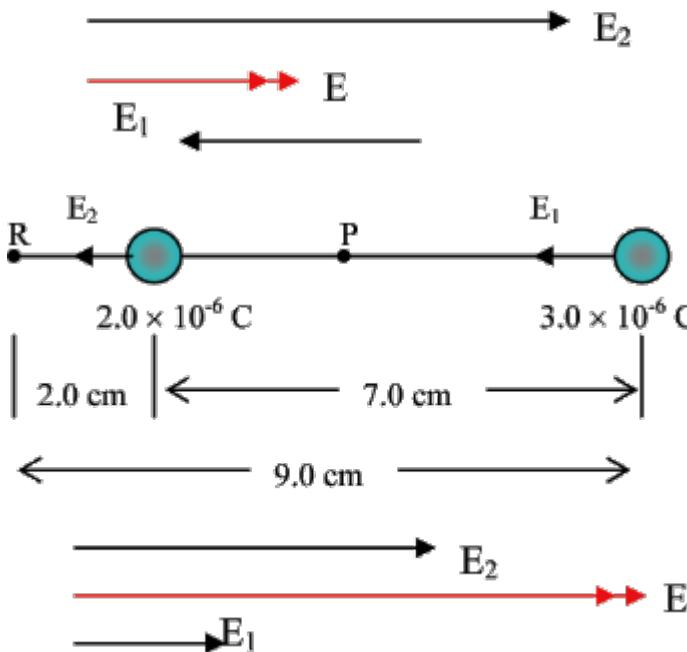
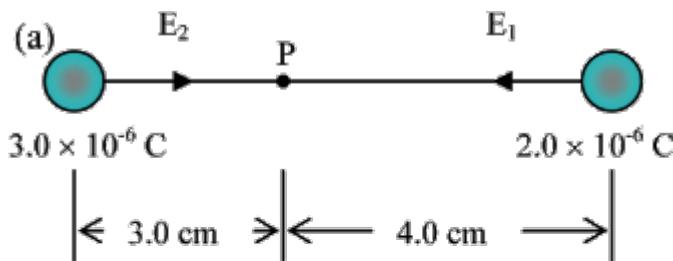
$$E_1 = \frac{1}{4\pi\epsilon_0} \frac{Q_1}{r_1^2} = \frac{9.0 \times 10^9 \times 3.0 \times 10^{-6}}{(9.0 \times 10^{-2})^2}$$

$$E_1 = 0.33 \times 10^7 \text{ N C}^{-1}.$$

Resultant electric field $E = E_2 - E_1$

$$E = 4.50 \times 10^7 \text{ N C}^{-1} + 0.33 \times 10^7 \text{ N C}^{-1}.$$

$$E = 4.83 \times 10^7 \text{ N C}^{-1}.$$



Electric potential

All points in an electric field of a charged particle have electric potential. The term "potential" means that a charge positioned in the field is capable of doing work.

Electric potential is the total work done or energy transformed in an electric field to bring a unit positive charge from a point at infinity (outside the field) to a point in the electric field of another charge.

Electric potential is the total work done or energy transformed in an electric field to bring a unit positive charge from a point at infinity (outside the field) to a point in the electric field of another charge.

Electric potential is a scalar quantity because its direction cannot be specified. It is the **work done per unit charge**, therefore,

$$\text{Electric potential} = \frac{\text{Work done}}{\text{Charge}}$$

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

Work done in moving a charge to a point r from the source of the charge Q is given by:

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

Q is the charge producing the field, q is the unit positive test charge, r is the distance of the test charge from Q and ϵ_0 is the permittivity of air. The closer the test charge q moves to the source of the charge Q , the greater the electric potential.

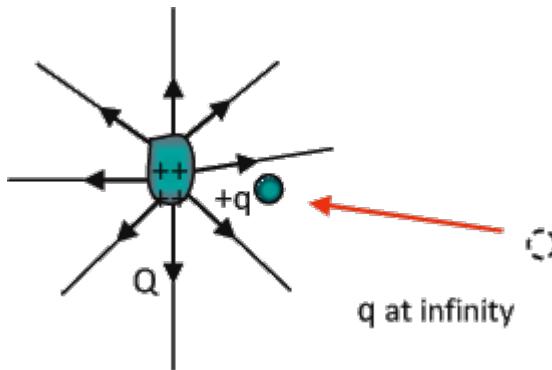


Figure 4.3 : Moving a positive charge q from infinity to the source of charge Q

Types of electric potential

1. Zero potential

All potentials around a charge are measured with respect to a chosen reference point. Conventionally, the reference point is taken as zero (0). Two reference points or zero potential selected for electric potentials are the **earth** and a **point at infinity** (outside the field under study). *Any object connected to the earth has zero potential; they are said to be earthed.* A positively charged object is at a higher potential than the earth. When it is earthed, electrons move from the earth towards the object. Negatively charged objects have lower potential than the earth; if connected to the earth, electrons move from such objects to the earth.

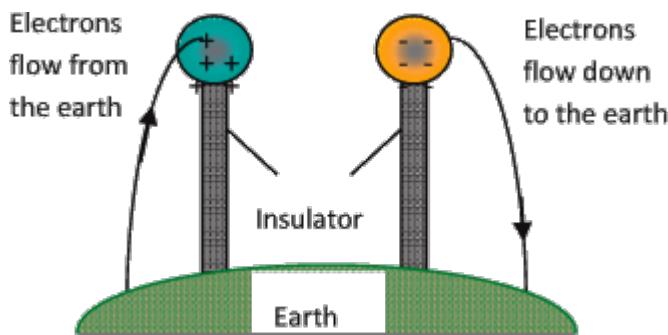


Figure 4.4: Electrons flow from the earth to a positively charged body and flow to the earth from a negatively charged body

2. Equipotential surface

Equipotential surface is an imaginary surface drawn in an electric field such that all points on the surface have the same electric potential.

An equipotential surface has the following characteristics:

- It is always the same distance from the source of the field.
- The electric lines of force or the field lines are always perpendicular to the surface.

- The work done in moving a unit positive charge along the surface is always zero. This is because points on this surface have the same potential.

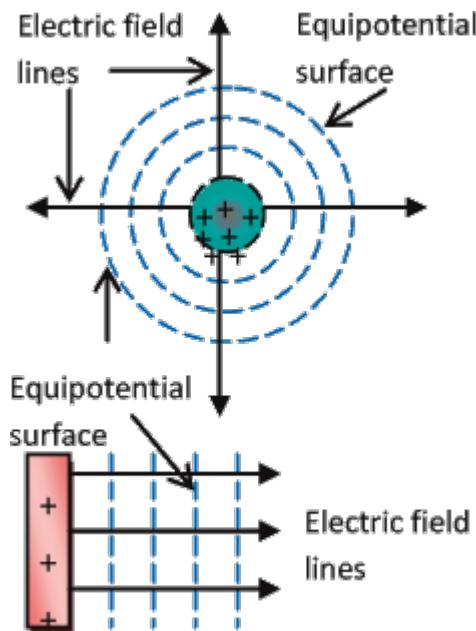


Figure 4.5: Equipotential surfaces

Potential difference (p.d.)

Potential difference (p.d.) is the work done or energy transformed per unit positive charge to move it from one point to another in the electric field.

The work done against the field in moving the charge q from the point A to another point B is the potential difference V_{ab} . This is given as:

$$V_{ab} = V_a - V_b$$

$$V_{ab} = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{b} - \frac{1}{a} \right) \text{ or } V_{ab} = \frac{Q}{4\pi\epsilon_0} \frac{(a-b)}{ab}$$

$$V_{ab} = \frac{1}{4\pi\epsilon_0} \frac{Q}{b} - \frac{1}{4\pi\epsilon_0} \frac{Q}{a}$$

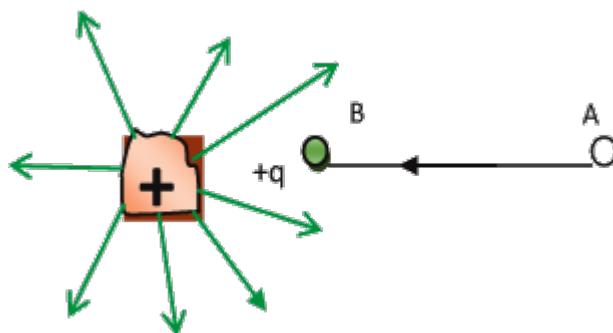


Figure 4.6 Moving positive charge q from A to B

The point â€˜bâ€™ is nearer to the charge, therefore is at a higher potential than the point â€˜aâ€™ . The unit of electric potential and electric potential difference is Volt (V). *Volt is*

the work done to move a unit charge through a unit distance (1 m).

Worked examples

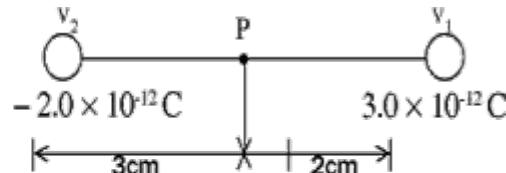
1. Two charges of magnitudes $-2.0 \times 10^{-12} \text{ C}$ and $3.0 \times 10^{-12} \text{ C}$ respectively are 5.0 cm from each other. Calculate the electric potential at a point:

- (a) between the charges and 2.0 cm from the positive charge.
- (b) outside the charges and 1.0 cm from the negative charge.

{Electrostatic constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ }

Solution

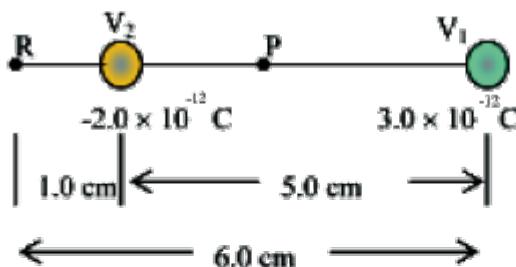
$$(a) V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r_1} + \frac{1}{4\pi\epsilon_0} \frac{Q}{r_2}$$



$$V = \frac{9.0 \times 10^9 \times 2.0 \times 10^{-12}}{3.0 \times 10^{-2}} + \frac{9.0 \times 10^9 \times 3.0 \times 10^{-12}}{2.0 \times 10^{-2}} = 0.60 + 1.35V = 1.95V$$

$$V = 0.6 + 1.35 = 1.95 \text{ V.}$$

(b)



$$V = \frac{9.0 \times 10^9 \times 2.0 \times 10^{-12}}{1.0 \times 10^{-2}} + \frac{9.0 \times 10^9 \times 3.0 \times 10^{-12}}{6.0 \times 10^{-2}}$$

$$= 1.80 + 0.45 = 2.25 \text{ volts.}$$

2. A unit test charge is 3.0 cm from the source of an electric field. Assuming the field is produced by a charge of magnitude $6.0 \times 10^{-12} \text{ C}$, calculate the electric potential difference when the test charge is 1.0 cm from the source of the field. {Electrostatic constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ }

Solution

$$V_{ab} = \frac{Q}{4\pi\epsilon_0} \frac{a-b}{ab}$$

$$V_{ab} = 9.0 \times 10^9 \times 6.0 \times 10^{-12} \frac{0.01 - 0.03}{0.01 \times 0.03}$$

$$V_{ab} = 3.6 \text{ volt.}$$

Relationship between electric field strength (E) and potential difference (V)

Figure 4.7 shows two charged parallel plates, the electric field intensity between the plates is uniform since the electric field lines are parallel. If a positive charge Q is placed in the field between the plates, a constant force (F) acts on the charge to move it towards the negative plate. The work done by the constant force on the charge is the product of the force and the charge.

$$\text{Work done} = \text{Force } \tilde{A} \text{— distance moved}$$

$$W = F \tilde{A} — d \dots\dots i$$

Work is done against the field if the positive charge is moved towards the positive plate against the attraction of the negative plate. This is given as

$$\text{Work done} = \text{Charge } \tilde{A} \text{— Potential difference}$$

$$W = Q \tilde{A} — V \dots\dots ii$$

Equation *i* and *ii* represent the same amount of work done on the charge.

$$F \tilde{A} — d = Q \tilde{A} — V \dots\dots iii$$

Rearranging equation *iii* results in

$$\frac{F}{Q} = \frac{V}{d}$$

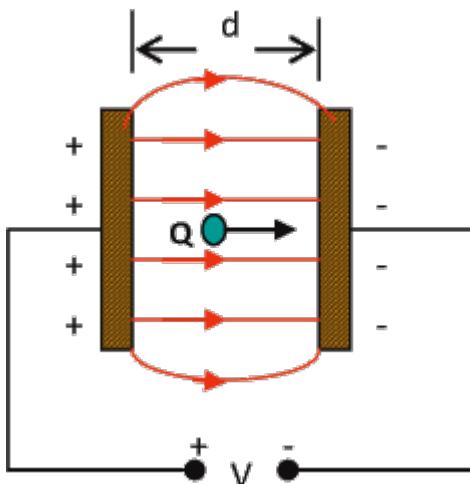


Figure 4.7: Potential difference between parallel plates

$$\frac{F}{Q} = E \text{ (electric field intensity or strength)}$$

$$\frac{V}{d}$$

= potential gradient. The unit of potential gradient is volt per metre (Vm^{-1}). It then means that the electric field intensity is equal to the potential gradient. Therefore;

$$E = \frac{V}{d}$$

Worked example

The plates of a parallel plate capacitor are 5 cm apart and are charged by applying a p.d.

of 100V. Calculate;

- (i) the electric field intensity between the plates.
- (ii) the force acting on a charge 2.0×10^{-6} C situated in the field.

Solution

$$(i) E = \frac{V}{d} = \frac{100}{0.05} = 2000 \text{ V m}^{-1}$$

$$(ii) F = qE = 2.0 \times 10^{-6} \times 2000 = 4.0 \times 10^{-3} \text{ N}$$

Summary

- **Matter** is made up of **electrically charged particles** which attract or repel each other.
- **Coulomb's law** states that the force of attraction or repulsion between two electric charges q_1 and q_2 is proportional to the product of the charges and inversely proportional to the square of the distance between them.

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

- **Electric field** is the region or space around a charge where electric force can be exerted on another charge.
- The electric field around any charged body is made up of many lines of force called electric field lines.
- An electric field line is the path traced by a small positive test charge as it moves in an electric field.
- **Electric field intensity or strength** is force acting on unit positive charge in an electric field

$$\text{Electric field intensity} = \frac{\text{Force}}{\text{Charge}}$$

The unit is NC^{-1} .

- **Electric potential** is the total work done or energy transformed in an electric field to bring a unit positive charge from a point at infinity (outside the field) to a point in the electric field of another charge.

$$\text{Electric potential} = \frac{\text{Work done}}{\text{Charge}}$$

The unit is JC^{-1} or Volt.

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

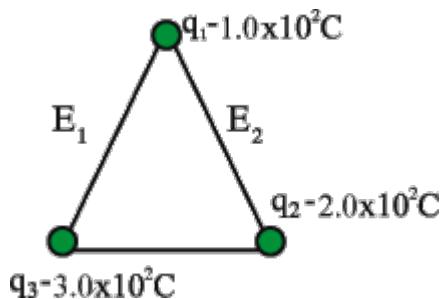
- **Zero potential** is the reference points to compare the electric potentials. The earth and a point outside the field under study (infinity) are the two zero potentials.
- An object connected to the earth has zero potential and is said to be **earthed**.
- **Equipotent surface** is an imaginary surface drawn in an electric such that all points

on the surface have the same electric potential.

• **Potential difference (p.d.)** is the work done or energy transformed per unit positive charge to move it from one point to another in the electric field.

Practice Questions 4a

1. (a). State Coulomb's law.
- (b). Two protons each of charge $1.67 \times 10^{-19} \text{ C}$ are $1.5 \times 10^{-15} \text{ m}$ apart. Calculate the electrostatic force of repulsion between them. {Electrostatic constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ }
2. (a). State the law of electrostatic charges.
- (b). How does the force of attraction between two charges depend on the:
 - (i) size of the charges?
 - (ii) distance between the charges?
- (c). Three charges q_1 , q_2 and q_3 are arranged on the apex of an equilateral triangle of sides 5.0 cm as shown below. Find the resultant force on the charge q_1 . {Electrostatic constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ }



3. (a). Explain what is meant by (i) *electric field* (ii) *electric field intensity*.
- (b). Two positively charged spheres with charges $5.0 \times 10^{-8} \text{ C}$ and $7.0 \times 10^{-8} \text{ C}$ respectively are separated by 10.0 cm; calculate the electric field intensity at a point:
 - (i) between the charges and 3.0 cm from the bigger charge;
 - (ii) outside the charges and 2.0 cm from the bigger charge. {Electrostatic constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ }
4. (a). Define:
 - (i) electric field intensity;
 - (ii) electric potential at a point in an electric field.
- (b). Two electrons each of charge $-1.6 \times 10^{-19} \text{ C}$ are $1.0 \times 10^{-12} \text{ cm}$ apart. Calculate for the electrons:
 - (i) the electric field intensity half-way between them;

- (ii) the electric potential half-way between the electrons. {Electrostatic constant $k = 9.0 \text{ N m}^2 \text{ C}^{-2}$ }
5. (a). What is *potential difference*?
(b). Explain what is meant by *equipotential surface* and *zero potential*.
(c). A small charge of size $1.2 \text{ } \tilde{\text{A}} - 10^{-6} \text{ C}$ is placed in a uniform electric field of intensity $1.44 \text{ } \tilde{\text{A}} - 10^5 \text{ NC}^{-1}$. Calculate the:
(i) force acting on the charge;
(ii) electric potential when the charge is 4 cm from the source of the field;
(iii) potential difference if the charge is moved to a new position 6 cm from the source of the field. {Electrostatic constant $k = 9.0 \text{ } \tilde{\text{A}} - 10^9 \text{ N m}^2 \text{ C}^{-2}$ }
- 6 (a). What is electric potential?
(b). How is electric potential related to electric field intensity?
(c). Two parallel plates are 5cm apart. A potential difference of 1000V connected across the plates moves a charge of $4.0 \text{ } \tilde{\text{A}} - 10^{-8} \text{ C}$ from one plate to the other. Calculate the:
(i) electric field intensity between the plates;
(ii) constant force acting on the charge.

Capacitor

OBJECTIVES

At the end of this topic, students should be able to:

- explain the term-capacitance of a capacitor;
- calculate the equivalent capacitance for a series and parallel arrangement of capacitors;
- determine the energy stored in capacitors.

A capacitor stores up electric charges. It consists of two parallel metal plates separated by an insulator or dielectric material. The plates have equal and opposite charges. A capacitor with a fixed capacitance is called fixed capacitors while those that their capacitance can be changed are called variable capacitors.

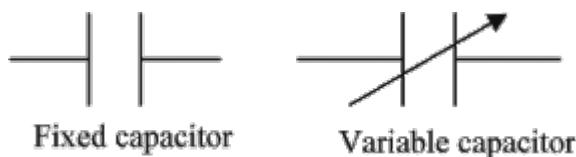


Figure 4.8 : Symbols of capacitor

Types of capacitors

The name given to a capacitor depends on its construction and the type of insulator or dielectric material placed between its plates. The following are examples of capacitors: paper capacitor, mica capacitor, ceramic capacitor, air capacitor and electrolytic capacitor.

Air-dielectric capacitor

An air capacitor consists of parallel plates separated by air as dielectric. It has a set of variable air plates and fixed plates. The variable plates are used to change the space of air – dielectric by moving the moveable plates in or out of the fixed plates. The relative position of the two plates makes the capacitance of the capacitor to change. Radio and television tuning circuit uses variable capacitors to select a channel of a particular station.

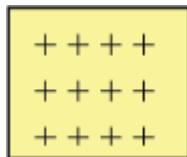
Uses of capacitors

We use capacitors in electrical circuits to:

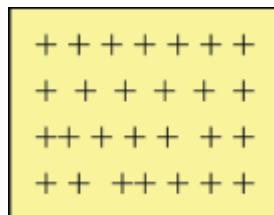
- tune the radio or television receivers to the station of our choice.
- make a rectified current from a.c. source smooth.
- prevent sparking in switches like car ignition relay.
- store up large amount of charge in research institutes.
- work as timers.

Capacitance of capacitor

Capacitance is the ability of a capacitor to store up electrical charges. A capacitor with large plates stores more charges than a capacitor with small plates. Capacitance is higher for capacitors with large plates.



Small plates store small charge and have lower capacitance



Large plates store more charge and have higher capacitance

The amount of charge stored on a fixed plate of a capacitor is proportional to the voltage applied across its terminal.

$$\text{Amount of charge stored} \propto \text{Voltage}$$
$$Q \propto V$$

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

Where C is the capacitance of the capacitor, it is a constant for a particular capacitor. Capacitance is the amount of charge stored per unit voltage.

Capacitance is the amount of charge stored per unit voltage. Or

$$\text{Capacitance} = \frac{\text{Charge stored}}{\text{Voltage}}$$

The unit of capacitance is Farad (F). Farad is a large unit; therefore, the units of practical capacitors are microfarad (μF) and picofarad (pF).

Farad is the capacitance of a capacitor which stores a coulomb of charge when a voltage of one volt is applied across it.

The capacitance of a parallel plate capacitor is given by $1\mu\text{F} = 1.0 \times 10^{-6} \text{ F}$ $1\text{pF} = 1.0 \times 10^{-12} \text{ F}$

Capacitance of a parallel plate capacitor

A parallel plate capacitor consists of two parallel metal plates each having a cross-sectional area A , separated by a small distance d . An insulator or dielectric is put in the gap between the plates to make the electric field intensity strong and uniform. When a voltage V volt is connected across the plates, electric charge Q is stored in the plates. by

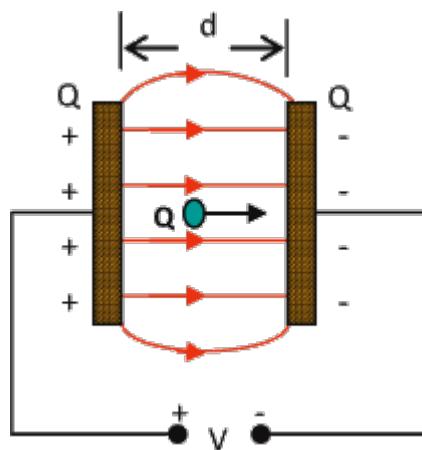


Figure 4.9 Parallel plate capacitor

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

C = capacitance of the capacitor

A = area of the plate of the capacitor

d = distance between the plates of the capacitor

ϵ_0 = permittivity of the insulator or dielectric material.

Good insulators are used because they make the electric field intensity strong. A stronger field produces higher capacitance.

Factors which determine the capacitance of a parallel plate capacitor

Three factors determining the capacitance of a parallel plate capacitor are:

1. Area of the plates (A) : A capacitor with large surface area stores more charge than a capacitor with a small surface area. *Capacitance increases as the area of the plate increases.*

2. Nature of the insulator between the plates (ϵ_0): A good insulator placed between the plates makes the capacitance of the capacitor to be high.

3.Distance (d) between the plates: Capacitance is inversely proportional to the distance between the plates (i.e. capacitance is high if the separation of the plates is small).

These factors can easily be recalled using the code **AND**.

Worked example

- 1 (a). What do you understand by the capacitance of a capacitor is 4.0 F ?
- (b). A capacitor consists of two parallel plates each of area 0.005 m^2 separated by a distance of 0.0001 m . Calculate the capacitance if the separation between the plates is filled with:
 - (i) air of permittivity $8.85 \times 10^{-12} \text{ F m}^{-1}$;
 - (ii) a material of permittivity $9.00 \times 10^{-8} \text{ F m}^{-1}$.

Solution

- (a). A capacitance of 4.0 F means that $4.0 \times 10^{-6} \text{ C}$ of charge is stored in the capacitor if a voltage of 1 V is connected across its terminal.

(b).

$$(i) \quad C = \frac{\epsilon A}{d}$$

C = capacitance of the capacitor

A = area of the plate of the capacitor

d = distance between the plates of the capacitor

ϵ = permittivity of the insulator or dielectric material

$$C = \frac{8.85 \times 10^{-12} \times 0.005}{0.0001} = 4.425 \times 10^{-16} \text{ F}$$

$$\mathbf{C = 442.5 \text{ pF}}$$

$$(ii) \quad C = \frac{9.00 \times 10^{-8} \times 0.005}{0.0001} = 4.50 \times 10^{-6} \text{ F}$$

$$\mathbf{C = 4.50 \mu\text{F}}$$

2. A parallel plate capacitor has an area of 0.0001 m^2 and the distance between the plates is 0.01 m . If the capacitor is charged to a voltage of 100 V , calculate the:

- (a) capacitance of the capacitor;
- (b) charge stored in each plate of the capacitor;
- (c) electric field intensity between the plates;
- (d) work done to move a charge of $2.0 \times 10^{-6} \text{ C}$ across the plates. (Permittivity of air of $8.85 \times 10^{-12} \text{ F m}^{-1}$)

Solution

$$(a) \quad C = \frac{\varepsilon A}{d}$$

C = capacitance

A = area of the plate

d = distance between the plates

ϵ = permittivity of air

$$C = \frac{8.85 \times 10^{-12} \times 0.0001}{0.01} = 8.85 \times 10^{-14} F$$

$$(b) \quad Q = CV = 8.85 \times 10^{-12} \times 100 \\ = 8.85 \times 10^{-12} \text{ C.}$$

$$(c) \quad C = \frac{V}{d} = \frac{100}{0.01} = 10,000 \text{ } Vm^{-1}$$

$$(d) \text{ Work done} = QV = 2 \times 10^{-6} \times 100 = 2 \times 10^{-4} \text{ J}$$

Energy stored in a capacitor

Capacitors store up charges or electrical energy when a voltage is connected across it. The voltage helps to separate the charges such that positive charges are stored on one plate and negative charges on the other plate. *The separation and storing of the charges in the plates is called charging.* Capacitors are charged using direct current as shown in Figure 4.9.

Work done in moving a charge Q from one plate to another by the voltage V is given by

Work done = Charge \tilde{A} — Potential difference

$$W = Q \tilde{A} - V$$

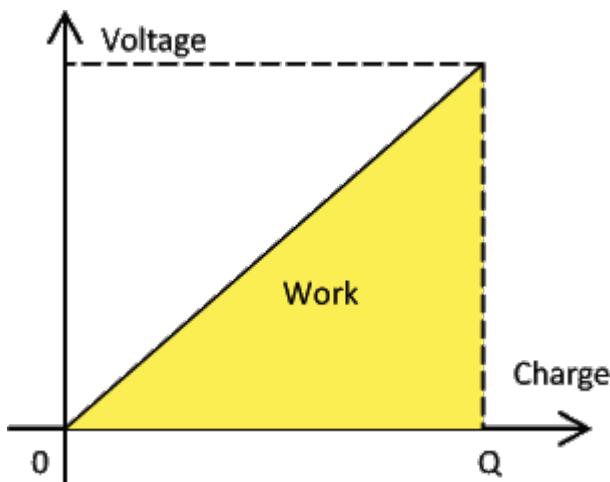


Figure 4.10 : Graph of voltage against charge

At the beginning of charging, work done is zero and at the end of charging, work done is QV . The energy stored in the capacitor is the average work done during charging. This is the area under the graph of voltage against charge as shown in figure 4.10. Energy stored = average work done

$$W = \frac{1}{2} QV \dots \text{.....i}$$

The charge stored by the capacitor $Q = CV$. Substituting $Q = CV$ in equation (i) gives:

$$\therefore W = \frac{1}{2}(CV)V$$

$$W = \frac{1}{2} C V^2 \dots .ii$$

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

Substituting C in equation (i)

$$W = \frac{1}{2} C \left(\frac{Q}{C} \right)^2$$

$$W = \frac{1}{2} \frac{Q^2}{C} \dots \dots \dots iii$$

Worked examples

1. A capacitor of $100\frac{1}{4}\text{F}$ is charged to a voltage of 12 volts. Find the energy stored in the capacitor.

Solution

$$\text{Capacitance } C = 100 \text{ }\mu\text{F} = 1.0 \text{ }\mu\text{A} - 10^{-4} \text{ F}$$

Voltage V = 12V

$$W = \frac{1}{2}CV^2 = \frac{1}{2} \times 1.0 \times 10^{-4} \times 12^2$$

$$W = 7.2 \text{ Å} - 10^{-3} J$$

2. A capacitor of $5\frac{1}{4}\text{F}$ stores a total charge of $2.0 \times 10^{-6}\text{ C}$. Calculate for the capacitor;

- (a) the energy stored.
 - (b) the voltage across the capacitor.

Solution

$$W = \frac{1}{2} \frac{Q^2}{C}$$

$$(a) W = \frac{1}{2} \times \frac{(2.0 \times 10^{-6})^2}{5 \times 10^{-6}} = 4.0 \times 10^{-7} \text{ J} \quad (b) W = \frac{1}{2} CV^2$$

$$4.0 \times 10^{-7} = \frac{1}{2} \times 5 \times 10^{-6} \times V^2$$

$$V^2 = \frac{4 \times 10^{-7} \times 2}{5 \times 10^{-6}} = 1.6 \times 10^{-1} \quad V = \sqrt{0.16} = 0.4 \text{ V}$$

Arrangements of capacitors

A capacitor can be connected in a circuit either in parallel, series or a combined parallel and series connection.

I. Capacitors connected in parallel

Capacitors are connected in parallel if they are arranged side by side with their positive terminals joined to common junction. Figure 4.11 shows two ways to arrange two capacitors in parallel.

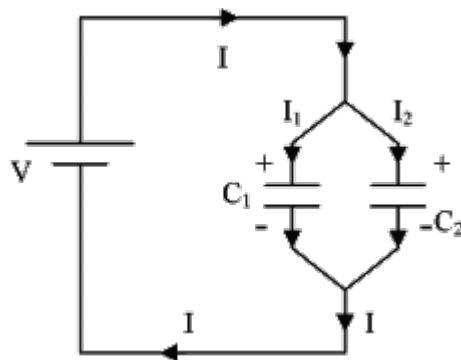


Figure 4.11a

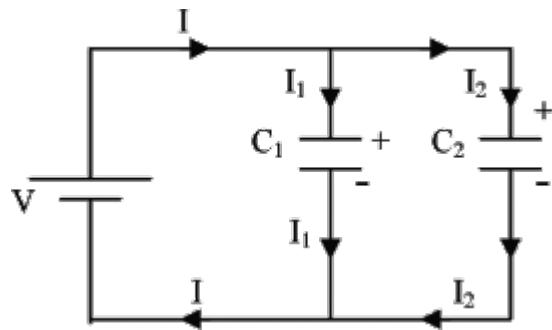


Figure 4.11b Capacitors in parallel

When capacitors are connected in parallel:

- the same voltage or potential difference is applied across each capacitor.
- the charge (Q) stored on the plate of the capacitors depends on the current passing through the capacitors and their capacitance.
- the total charge stored by the capacitors in parallel is the sum of charges stored by each capacitor.

$$\text{Total charge } Q = Q_1 + Q_2$$

$$\text{The charge stored in a capacitor } Q = CV, Q_1 = C_1V \text{ and } Q_2 = C_2V.$$

$$\hat{\wedge}CV = C_1V + C_2V$$

$$C = C_1 + C_2 + \hat{\epsilon}$$

C is the total or the effective capacitance of the combination in parallel. *The effective capacitance of capacitors connected in parallel is the sum of the capacitances.*

II. Capacitors connected in series:

Capacitors are connected in series if they are connected end to end such that they form a complete loop. Series arrangement is shown in Figure 4.12.

When capacitors are connected in series:

- the same amount of charge Q is stored on each capacitor since the same current flows through each capacitor.

- the voltage through each capacitor depends on the capacitance of the capacitor.
- the total voltage is the sum of the voltages across the capacitors.

$$V = V_1 + V_2$$

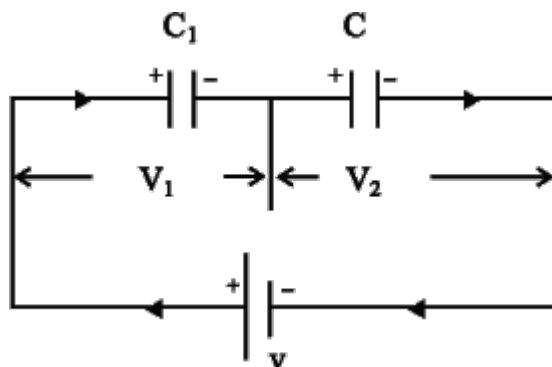


Figure 4.12 Capacitors in series

Now $V = \frac{Q}{C}$, $V_1 = \frac{Q}{C_1}$ and $V_2 = \frac{Q}{C_2}$

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \text{ or } C = \frac{C_1 C_2}{C_1 + C_2}$$

The effective or total capacitance (\$C\$) for a series arrangement is decreased as more capacitors are connected in series. The formula above can be extended to any number of capacitors in series.

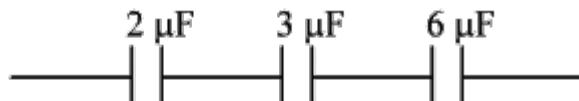
Worked examples

1. Three capacitors of capacitances $2\frac{1}{4}\mu F$, $3\frac{1}{4}\mu F$ and $6\frac{1}{4}\mu F$ respectively are connected in
 (i) series (ii) parallel.

Find the total capacitance in each arrangement.

Solution

(i)

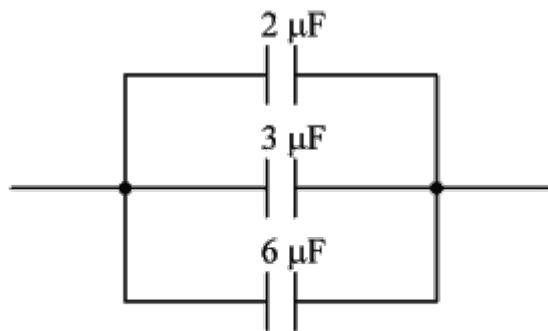


$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{6+4+2}{12} = \frac{12}{12}$$

$$C = 1\mu F$$

(ii)



$$C = C_1 + C_2 + C_3$$

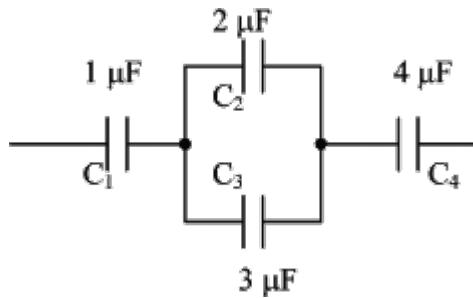
$$C = 2 \mu F + 3 \mu F + 6 \mu F = 11 \mu F$$

2. Two capacitors are connected in series such that their total capacitance is $2\frac{1}{4}F$. If the capacitance of one of the capacitor is $6\frac{1}{4}F$, find the capacitance of the other capacitor.

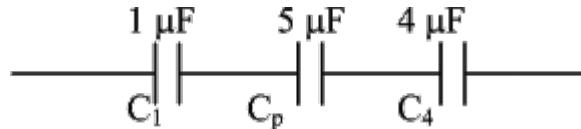
Solution

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \quad \frac{1}{2} = \frac{1}{6} + \frac{1}{C_2} \quad \frac{1}{C_2} = \frac{1}{2} - \frac{1}{6} = \frac{3-1}{6} = \frac{2}{6} \quad C_2 = \frac{6}{2} = 2 \mu F$$

3. The circuit below shows the arrangement of four capacitors, what is the effective capacitance of the arrangement?

**Solution**

$$\text{Total capacitance in parallel } C_p = C_2 + C_3 \quad C_p = 2+3 = 5\frac{1}{4}F$$



The capacitors are reduced to three series capacitors C_1 , C_p and C_4 as shown in the diagram.

The effective capacitance is now calculated using the formula;

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_p} + \frac{1}{C_4} = \frac{1}{1} + \frac{1}{5} + \frac{1}{4} \quad \frac{1}{C} = \frac{20+4+5}{20} = \frac{29}{20} \quad C = \frac{20}{29} = 0.69 \mu F$$

4. Three capacitors having the capacitances of $10\frac{1}{4}F$, $5\frac{1}{4}F$ and $20\frac{1}{4}F$ respectively are connected in series to a 12 volt d.c. supply. Calculate the:

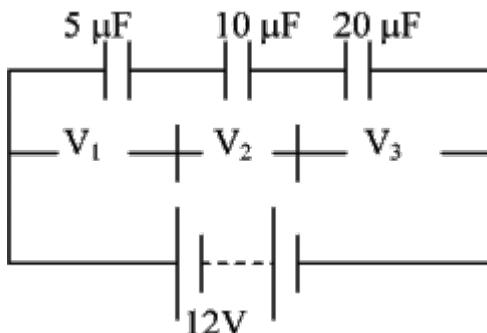
- (i) combined capacitance of the capacitors.
- (ii) voltage across each capacitor.
- (iii) energy stored in the $10\frac{1}{4}\text{F}$ capacitor.

Solution

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

$$\frac{1}{C} = \frac{1}{5} + \frac{1}{10} + \frac{1}{20} = \frac{4+2+1}{20} = \frac{7}{20}$$

$$C = \frac{20}{7} = 2.86\mu\text{F}$$



The total charge stored in the capacitor Q is given by $Q = CV = 2.86 \times 10^{-6} \times 12 = 34.32 \times 10^{-6} \text{ C}$.

$$(ii) V_1 = \frac{Q}{C_1} = \frac{34.32 \times 10^{-6}}{5 \times 10^{-6}} = 6.86\text{V}$$

$$V_2 = \frac{Q}{C_2} = \frac{34.32 \times 10^{-6}}{10 \times 10^{-6}} = 3.43\text{V}$$

$$V_3 = \frac{Q}{C_3} = \frac{34.32 \times 10^{-6}}{20 \times 10^{-6}} = 1.72\text{V}$$

$$(iii) W = \frac{1}{2} C_2 V_2^2 = \frac{1}{2} \times 10 \times 10^{-6} \times 3.43^2$$

$$W = 5.88 \times 10^{-5} \text{ J}$$

Summary

- **Capacitors** store up electric charges. Capacitors consist of two parallel metal plates separated by an insulator or dielectric material.
- **Capacitance** is the amount of charge stored per unit voltage. Or

$$\text{Capacitance} = \frac{\text{Charge stored}}{\text{Voltage}}$$

- The capacitance of a capacitor depends on: **area of the plates (A)**, **nature of the insulator** between the plates (e) and **distance (d)** between the plates.
- Energy stored = average work done**

$$W = \frac{1}{2} QV$$

$$W = \frac{1}{2} \left(\frac{Q^2}{C} \right)$$

$$W = \frac{1}{2} CV^2$$

- In a parallel circuit;**

the same voltage or potential difference is applied across each capacitor.

the charge (Q) stored on the plate of the capacitors depends on the current passing through the capacitors and their capacitance.

$$C = C_1 + C_2 + C_3$$

- In a series circuit;**

- the same amount of charge Q is stored on each capacitor since the same current flows through each capacitor.

- the voltage through each capacitor depends on the capacitance of the capacitor.

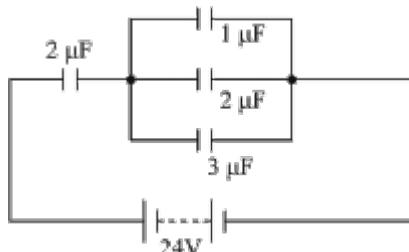
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Practice Questions 4b

- (a). What is a capacitor?
 (b). Give **three** applications of a capacitor.
- (a). Define the capacitance of a capacitor.
 (b). State **three** factors which determine the capacitance of a capacitor. State how the capacitance of the capacitor depends on these factors.
 (c). A parallel plate capacitor has plates each of area $3.2 \times 10^{-4} \text{ m}^2$ and are $1.0 \times 10^{-5} \text{ m}$ apart. If a perspex of permittivity $3.2 \times 10^{-11} \text{ F m}^{-1}$ is inserted between the plates, find the capacitance of the capacitor.
- (a). What do you understand by the capacitance of a capacitor is $2\frac{1}{4} \text{ F}$?
 (b). The parallel plates of a capacitor are $5.0 \times 10^{-3} \text{ m}$ apart and the area of each plate is $2.0 \times 10^{-6} \text{ m}^2$. If an insulator of permittivity $2.5 \times 10^{-11} \text{ F}$

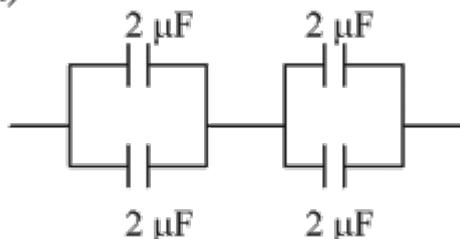
m^{-1} is inserted between the plates and a p.d. of 1000 V applied across them; calculate the:

- (i) capacitance of the capacitor;
 - (ii) charge stored on each plate of the capacitor;
 - (iii) energy stored in the capacitor.
 - (iv) energy stored in the capacitor.
4. (a). What do you understand by the capacitance of a capacitor?
- (b). Two capacitors of capacitance $2\frac{1}{4}\text{F}$ and $3\frac{1}{4}\text{F}$ are connected in series to a 6 volt supply. Find the:
- (i) combined capacitance of the capacitor;
 - (ii) voltage measured across each capacitor;
 - (iii) energy stored in each capacitor.
5. The circuit below shows the arrangement of four capacitors. Calculate the:
- (i) effective capacitance of the capacitors.
 - (ii) total charge stored by the capacitors.
 - (iii) voltage across the $3\frac{1}{4}\text{F}$ capacitor.
 - (iv) energy stored in the $3\frac{1}{4}\text{F}$ capacitor.

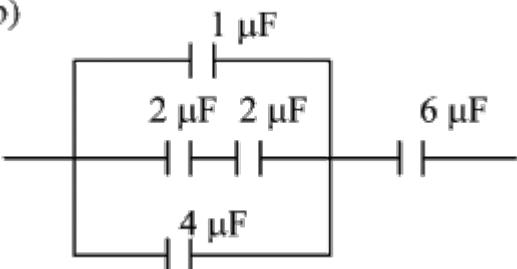


6. Calculate the effective capacitance of the following circuits below.

(a)



(b)



Past questions

1. If the quantity of electric charge on each of the two point charges is doubled, the electrostatic force between the charges will
 - A. remain the same.
 - B. be halved.
 - C. be doubled.
 - D. be quadrupled.

WASSCE

2. An electron of charge $1.6 \times 10^{-19} \text{ C}$ is accelerated between two metal plates. If the kinetic energy of the electron is $4.8 \times 10^{-17} \text{ J}$, the potential difference between the plates is
 - A. 400 V
 - B. 300 V
 - C. 30 V
 - D. 40 V

JAMB

3. A charge of $1.6 \times 10^{-10} \text{ C}$ is placed in a uniform electric field of intensity $2.0 \times 10^5 \text{ N C}^{-1}$.

Determine the magnitude of the electric force exerted on the charge.

- A. $3.2 \times 10^5 \text{ N}$
- B. $1.8 \times 10^5 \text{ N}$
- C. $3.2 \times 10^{-5} \text{ N}$
- D. $1.8 \times 10^{-5} \text{ N}$

WASSCE

4. Two electric point-charges are separated by a very small distance, r . Which of the following statements is not correct? The
 - A. magnitude of the electrostatic force between them is inversely proportional to r^2 .
 - B. direction of the force between them is along the straight line passing through them.
 - C. electric lines of force around each charge are concentric.
 - D. electrostatic field around them is a force field.

WASSCE

5. What is the magnitude of the electric field intensity between two plates 30 cm apart, if the p.d. between the plates is 4.2 V?
 - A. 126.0 V m^{-1} .
 - B. 14.0 V m^{-1} .

- C. 12.6 V m^{-1} .
- D. 3.6 V m^{-1} .
- E. 1.4 V m^{-1} .

NECO 2002

6. A charge of $4 \mu\text{C}$ is placed 3 m away from a point P. Calculate the magnitude of the electric field intensity, due to the charge, at the point P.

$$\left[\frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ N m C}^{-1} \right]$$

- A. $8.1 \times 10^4 \text{ V m}^{-1}$.
- B. $2.7 \times 10^4 \text{ V m}^{-1}$.
- C. $1.2 \times 10^4 \text{ V m}^{-1}$.
- D. $4.0 \times 10^3 \text{ V m}^{-1}$.

WASSCE

7. In a uniform electric field, the magnitude of the force on a charge 0.2 C is 4 N. Calculate the electric field intensity.

- A. 20 N C^{-1} .
- B. 8 N C^{-1} .
- C. 5 N C^{-1} .
- D. 2 N C^{-1} .

WASSCE

8. A point charge of magnitude $2 \mu\text{C}$ is moved through a distance of 0.20 m against a uniform field of intensity 25 V m^{-1} . Calculate the work done on the charge.

- A. $5.0 \times 10^{-6} \text{ J}$
- B. $1.0 \times 10^{-5} \text{ J}$
- C. $5.0 \times 10^{-5} \text{ J}$
- D. $1.0 \times 10^{-2} \text{ J}$

WASSCE

9. The electric force between two points charges each of magnitude q and at a distance r apart in air of permittivity ϵ_0 is

A. $\frac{q^2}{4\pi\epsilon_0 r}$

D. $\frac{qr^2}{\epsilon_0}$

B. $\frac{q}{4\pi\epsilon_0 r}$

E. $\frac{q^2}{4\pi\epsilon_0 r^2}$

C. $\frac{4\pi q}{\epsilon_0}$

Waec

10. The force of repulsion between two point positive charges 5 C and 8 C charges separated at a distance of 0.02m apart is

A. $1.8 \times 10^{-10} \text{ N}$.

B. $9.0 \times 10^{-8} \text{ N}$.

C. $9.0 \times 10^2 \text{ N}$.

D. $4.5 \times 10^3 \text{ N}$.

Jamb

11. The ratio of electrostatic force F_E to gravitational force F_G between two protons each of charge e and mass m , at a distance d is

A. $\frac{e}{4\pi\epsilon_0 Gm}$

B. $\frac{e^2}{Gm^2}$

C. $\frac{Gm^2}{4\pi\epsilon_0 e^2}$

D. $\frac{e^2}{4\pi\epsilon_0 Gm^2}$

Jamb

12. Two capacitances of 6F and 8F are connected in series. What additional capacitance must be connected in series with this combination to give a total of 3F ?

A. 3F

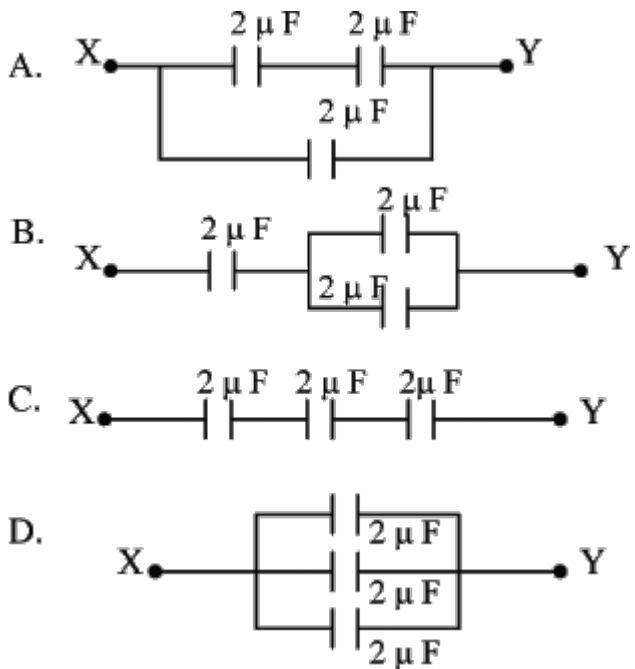
B. 16F

C. 24F

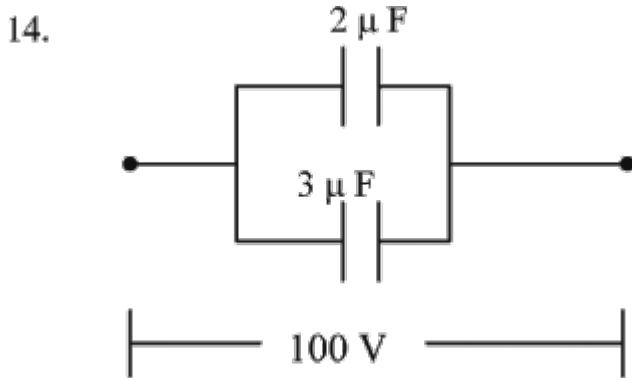
D. 30F

Jamb

13. Which of the following combinations of 2F capacitors will give an effective capacitance of 3F across terminal XY?



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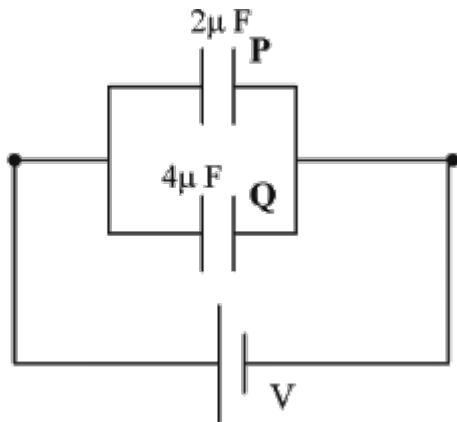


In the circuit above, the potential difference across each capacitor is 100 V. The total energy stored in the two capacitors is

- A. $3.0 \times 10^4 \text{ J}$
- B. $3.0 \times 10^2 \text{ J}$
- C. $2.5 \times 10^{-2} \text{ J}$
- D. $6.0 \times 10^{-3} \text{ J}$

JAMB

15.



The diagram above shows two capacitors **P** and **Q** of capacitances $2\frac{1}{4}\text{F}$ and $4\frac{1}{4}\text{F}$ respectively connected to a d.c. source. The ratio of energy stored in **P** to **Q** is

- A. 4:1
- B. 2:1
- C. 1:4
- D. 1:2

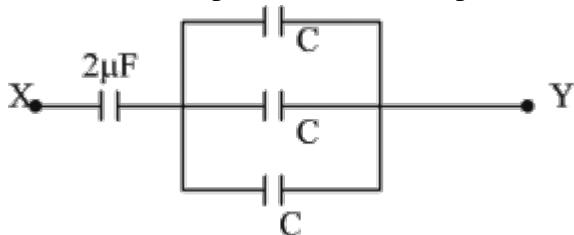
JAMB

16. The energy stored in a capacitor of capacitance $5\frac{1}{4}\text{F}$ is 40 J. What is the voltage applied across its terminals?

- A. 4 V
- B. 8 V
- C. 16 V
- D. 200 V
- E. 4000 V

NECO

17. The effective capacitance between points X and Y in the diagram below is $1.50\frac{1}{4}\text{F}$.



What is the value of the capacitance C?

- A. $0.5\frac{1}{4}\text{F}$
- B. $1.0\frac{1}{4}\text{F}$
- C. $2.0\frac{1}{4}\text{F}$
- D. $4.0\frac{1}{4}\text{F}$
- E. $5.0\frac{1}{4}\text{F}$

NECO

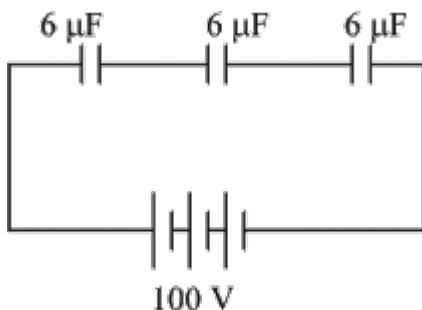
18. The potential difference across a parallel plate capacitor is 500V while the charge on either plate is $12 \frac{1}{4} \text{C}$. Calculate the capacitance of the capacitor.
- $6.0 \times 10^{-3} \text{ F}$
 - $2.4 \times 10^{-4} \text{ F}$
 - $6.0 \times 10^{-5} \text{ F}$
 - $2.4 \times 10^{-8} \text{ F}$

WASSCE

19. As the plates of a charged variable capacitor are moved closer together, the potential difference between them
- increases.
 - decreases.
 - remains the same.
 - is doubled.
20. The capacitance of a parallel-plate capacitor is increased by making the area of the plates
- small and their separation large.
 - large and their separation small.
 - and their separation small.
 - and their separation equal.

WASSCE

Use the diagram shown below to answer Questions 21 and 22.



21. What is the effective capacitance in the circuit?
- $2\frac{1}{4}\text{F}$
 - $6\frac{1}{4}\text{F}$
 - $18\frac{1}{4}\text{F}$
 - $216\frac{1}{4}\text{F}$

WASSCE

22. What is the total energy stored by the capacitors?
- $2.0 \times 10^{-4} \text{ J}$

- B. $1.0 \text{ A} = 10^{-4} \text{ J}$
- C. $9.0 \text{ A} = 10^{-2} \text{ J}$
- D. $1.0 \text{ A} = 10^{-2} \text{ J}$

WASSCE

23 (a) (i). Explain *electrostatic induction*.

- (ii). Define *capacitance* of a parallel plate capacitor.
- (iii). List **three** factors which can affect the capacitance of a parallel plate capacitor.

(b). State **three** applications of a capacitor.

- (c). A parallel plate capacitor consists of two identical plates of area $1.00 \text{ A} = 10^{-2} \text{ m}^2$ placed at a distance of $2.00 \times 10^{-2} \text{ m}$ apart in air. The capacitor is charged so that the potential difference between the plates is 1000 V. Calculate the
 - (i) magnitude of the electric field strength between the plates;
 - (ii) capacitance of the capacitor;
 - (iii) energy stored in the capacitor. {Neglect the edge effect, $\hat{\mu}_0 = 8.854 \text{ A} = 10^{-12} \text{ F m}^{-1}$ }

WASSCE

24 (a). Explain the statement *the capacitance of a capacitor is $5\frac{1}{4}F$* .

- (b) (i). State the factors upon which the capacitance of a parallel plate capacitor depend.
(ii). State how the capacitance depends on each of these factors stated in (b) (i).

(c). A series arrangement of three capacitors of values $8\frac{1}{4}\text{F}$, $12\frac{1}{4}\text{F}$ and $24\frac{1}{4}\text{F}$ is connected in series with a 90-V battery.

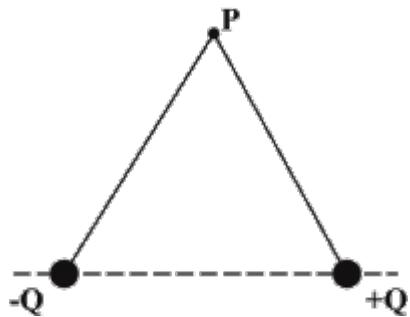
- (i) Draw an open-circuit diagram for the arrangement.
- (ii) Calculate the effective capacitance in the circuit.
- (iii) On closed circuit, calculate the charge on each capacitor when fully charged.
- (iv) Determine the p.d. across the $8\frac{1}{4}\text{F}$ capacitor.

WASSCE

25 (a). Define the following terms:

- (i). Electric field intensity
- (ii). Electric potential

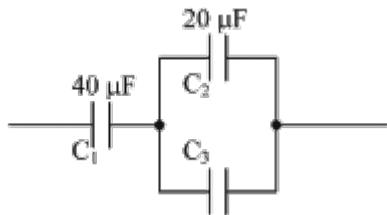
(b) The diagram below illustrates two collinear electric charges of magnitudes $+Q$ and $-Q$. The charges are equidistant from a point P at which a rest charge is placed.



Copy the diagram and use arrows to indicate, from the point P, the direction of the

- (i) electric force \mathbf{F}_1 due to $+Q$.
 - (ii) electric force \mathbf{F}_2 due to $-Q$.
 - (iii) electric field intensity \mathbf{E} .
- (c) (i). What is meant by *dielectric substance*?
(ii). List the factors which determine the capacitance of a parallel plate capacitor and state the effect each of them has on the capacitance.

(iii).



The diagram above represents a section of a circuit. Calculate the effective capacitance in the section.

WASSCE

26. (a). Define the **capacitance** of a capacitor.
(b). State (i) **THREE** factors on which the capacitance of a parallel-plate capacitor depends;
(ii). **TWO** uses of capacitors.
(c) The plates of a parallel-plate capacitor are 5 mm apart and 2 m^2 in area. The plates are in a vacuum. A potential difference of 1000 V is applied across the capacitor. Calculate the:
(i) capacitance,
(ii) charge on each plate,
(iii) electric field intensity in the space between them,
(iv) energy stored in the capacitor. {Permittivity of free space $\epsilon_0 = 8.854 \times 10^{-12} \text{ F m}^{-1}$ }

NECO

27. (a). Explain what is meant by the statement: *The capacitance of a capacitor is*

$2\frac{1}{4}F$.

(b). State:

- (i) **three** factors on which its capacitance depends;
 - (ii) **three** uses of capacitors.
- (c). Derive a formula for the energy W stored in a charged capacitor of capacitance C carrying a charge Q on either plate.
- (d). Two parallel-plate capacitors of capacitances $2\frac{1}{4}F$ and $3\frac{1}{4}F$ are connected in parallel and the combination is connected to a 50 V d.c. source. Draw the circuit diagram of the arrangement and determine the:
- (i) charge on either plate of the capacitor.
 - (ii) potential difference across each capacitor.
 - (iii) energy of the combined capacitor.

WAEC

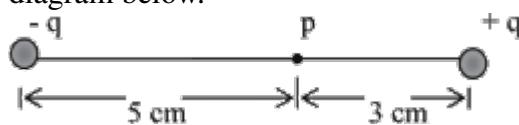
28. (a). Define the capacitance of a capacitor.

- (b). State **three** factors on which the capacitance of a parallel-plate capacitor depends.
- (c). Derive a formula for the energy W stored in a charged capacitor of capacitance C carrying a charge Q on either plate.
- (d). Two capacitors of capacitances $4\frac{1}{4}F$ and $6\frac{1}{4}F$ are connected in series to a 100 V d.c. supply. Draw the circuit diagram and calculate the:
- (i) charge on either plate of each capacitor.
 - (ii) p.d. across each capacitor.
 - (iii) energy stored of the combined capacitors.

WAEC

29. (a). Explain what is meant by:

- (i) *electric field intensity*,
 - (ii) *electric lines of force*.
- (b). Two similar but opposite point charges $-q$ and $+q$ each of magnitude 5.0×10^{-8} C are separated by a distance of 8.0 cm in a vacuum as shown in the diagram below.

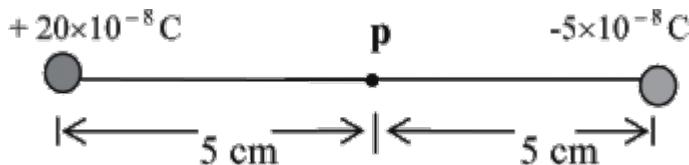


Calculate the magnitude and direction of the resultant electric field intensity E at the point P. Draw the lines of the force due to this system of charges.

WAEC

30. (a) Define the following terms:

- (i) electric field intensity
 - (ii) electric potential
- (b) If a gold leaf electroscope is charged and left, the leaves gradually collapse. Give **TWO** reasons for this.
- (c) Two point charges of magnitude $+20 \times 10^{-8} \text{ C}$ and $-5 \times 10^{-8} \text{ C}$ are separated by a distance of 10 cm in vacuum as shown in the diagram below.



Calculate:

- (i) the electric field intensity at the point **P**, midway between the charges;
- (ii) the force on a $-4 \times 10^{-8} \text{ C}$ charge placed at **P**.

$$\left[\text{Take } \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \right]$$

NECO

31. (a) (i) Explain
- (i) electric potential (II) electric potential energy.
 - (ii) State the unit of each of the terms in (a) (i) above.
- (b) An isolated electrically-charged sphere of radius, r , and charge, Q , is supported on an insulator in air of permittivity, ϵ_0 . Write down
- (i) an expression for the electric field intensity on the surface of the sphere;
 - (ii) an expression for the *electric potential* at the surface of the sphere;
 - (iii) a relationship between the *electric field intensity* and *electric potential* at the surface of the sphere.
- (c) The plates of a parallel plate capacitor, $5.0 \times 10^{-3} \text{ m}$ apart are maintained at a potential difference of $5.0 \times 10^4 \text{ V}$. Calculate the magnitude of the
- (i) electric field intensity between plates;
 - (ii) force on the electrons;
 - (iii) acceleration of the electron. [Electronic charge = $1.60 \times 10^{-19} \text{ C}$, mass of electron $9.1 \times 10^{-31} \text{ kg}$]

WASSCE