SAMUEL ADEGBOYEGA UNIVERSITY, OGWA
COLLEGE OF BASIC AND APPLIED SCIENCES
DEPARMENT OF MATHEMATICS AND PHYSICAL SCIENCES

PHY 122: ELECTRICITY AND MAGNETISM AND MODERN PHYSICS

LECTURE NOTE 2: ELECTROSTATICS

ELECTROSTATICS

Electrostatics refers to the branch of physics that studies static electrical charges or charges at rest.
In other words, it is the study of electric field from static charge distribution

The interaction of charges in an electrostatic field is analogous to that of masses in a gravitational field. These charges have forces engaged on them and therefore have potential energy (P.E.).

Production of Charges

Electrical charges are often made by

i. Contact
ii. Friction, and
iii. Induction.

Types of Charges

Two varieties of charges: positive charge (+) and negative charge (-).
This classification was named after American scientist called Benjamin Franklin.

Illustration

(I) if a glass rod is rubbed with a silk fabric, it acquires positive charge whereas the silk fabric acquires an equal quantity of negative charge.

(II) if an ebonite rod (hard rubber) is rubbed with fur, it becomes negatively charged, whereas the fur acquires an equal quantity of positive charge.

Fundamental law of Electrostatics

The fundamental law of electrostatics is thus

‘Like charges repel and unlike charges attract each other’

Conductors and Insulators

Materials can be classified into 2 categories, namely:

Conductors and insulators (dielectrics).

i. Bodies which permit the charges to go through are called conductors. E.g. metals (such as iron, copper, aluminum etc.), and so on.

ii. Materials that do not allow the charges to go through are referred to as insulators or dielectrics. Example are plastic, mica, glass, ebonite, and many others.

Coulomb’s Law

Coulomb’s law states that the force (of attraction or repulsion) between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance of separation between them. The forces act along the line joining the two point charges.

Coulomb's Law (Cont'd)

- Let q_1 and q_2 be two point charges placed in air medium at a distance r apart. Then, according to Coulomb's law,

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

Where k is the proportionality constant.

In air or vacuum, $K = \frac{1}{4\pi\varepsilon_0}$,

where ε_o is the permittivity of free space and $\varepsilon_o = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ N\ m^2\ C^{-2}$

$$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Electric Field

Electric field is defined as the region or space in which a charged body can experience a force

Electric lines of force

Electric line of force is an imaginary straight or curved path along which a unit positive charge tends to move in an electric field.

Properties of Lines of Forces

i. Lines of force start from the positive charge and terminate at the negative charge.

ii. Lines of force never intersect.

iii. The tangent to a line of force at any point indicates the path of the electric field (E) at that point.

iv. The number of lines of force traversing a unit area is proportional to the magnitude of intensity, E. This implies that anywhere the lines of force are close together, the magnitude of E is large and when they are far away, E is of small magnitude.

v. Lines of force are always normal to the surface of the body at the point where they start or terminate

vi. There is a tendency of contraction along the length of the lines of force.

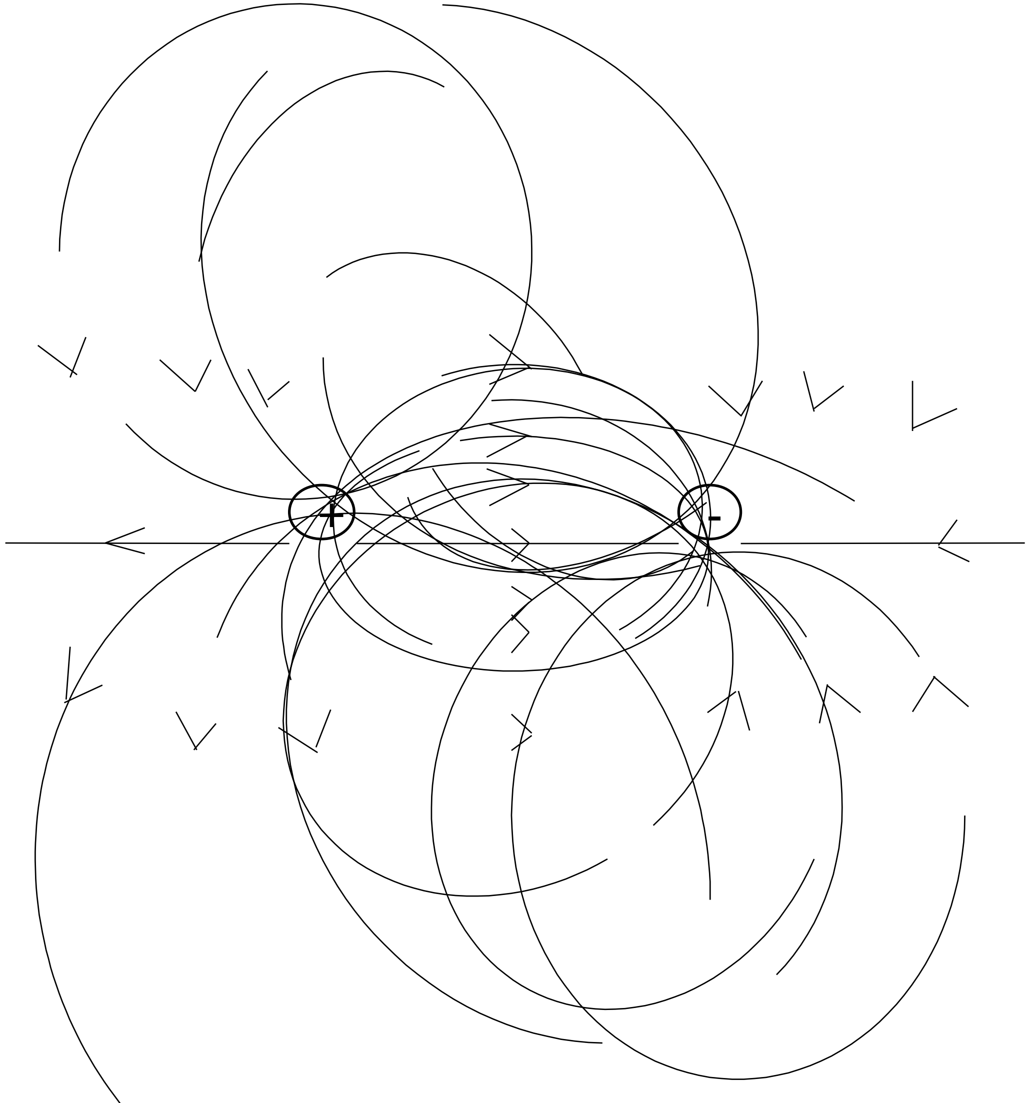
Pattern of the Electric Field

(a) (b)

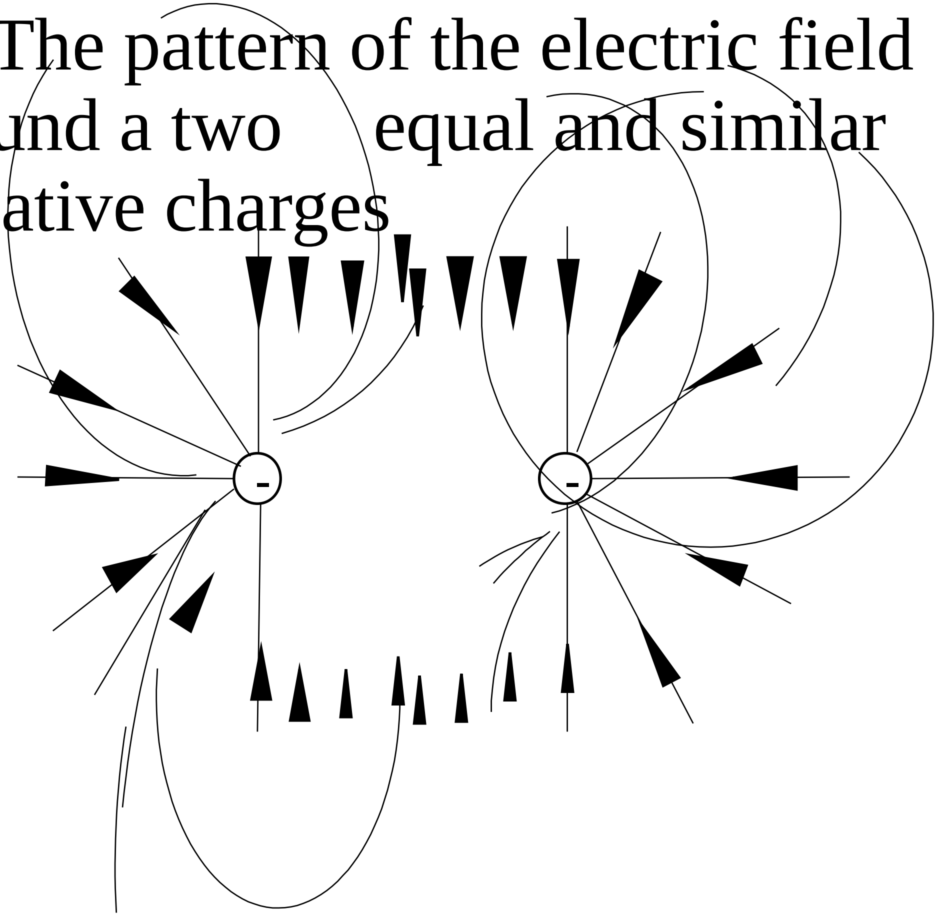
a) The pattern of the electric field around a positive charge

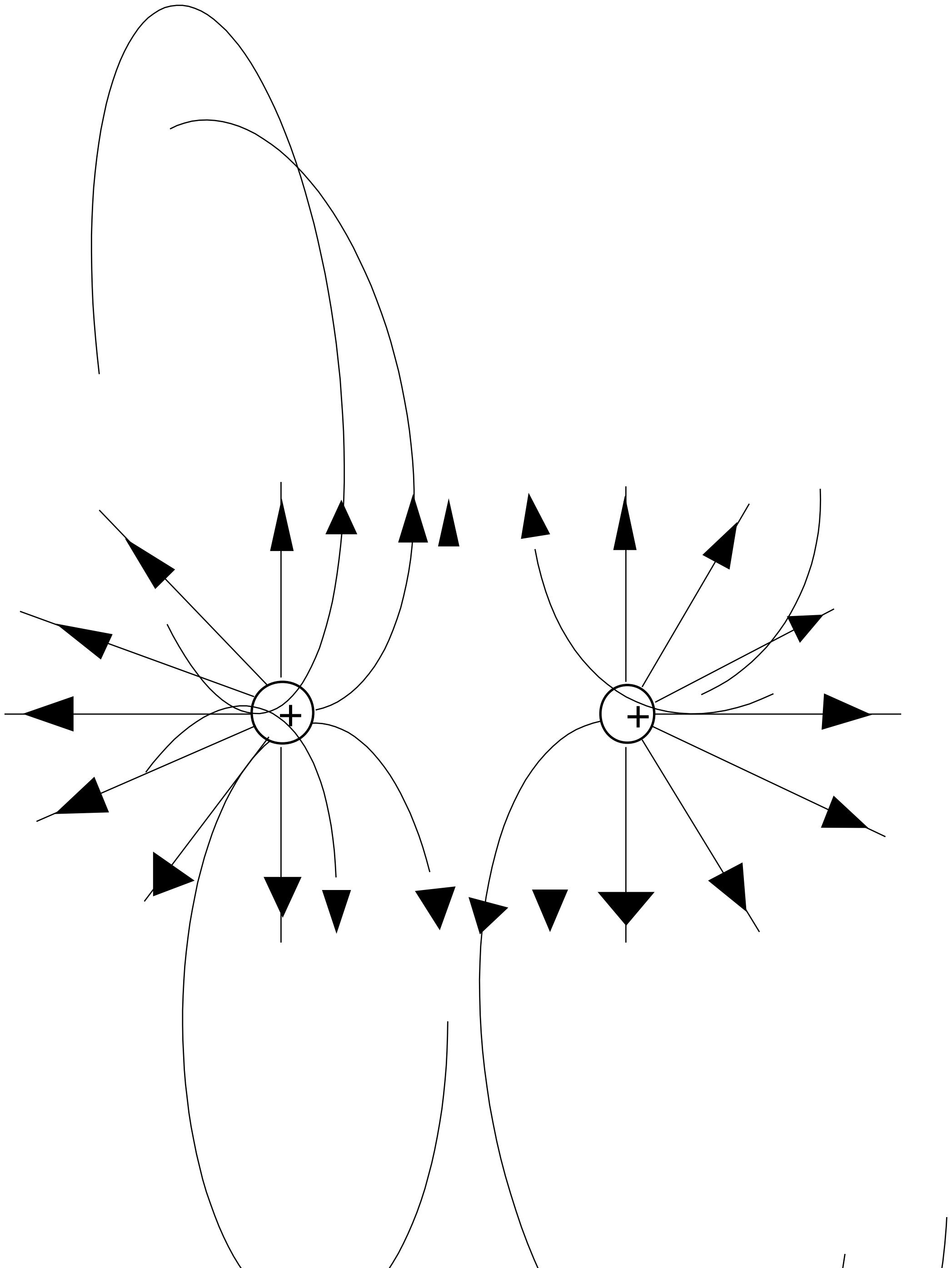
b) The pattern of the electric field around a negative charge

Pattern of the Electric Field



d) The pattern of the electric field around a two equal and similar negative charges





Electric Field Strength or Intensity

Electric field strength at a given point id defined as the force experience by a unit positive charge placed at that point.

$$E = \frac{F}{q_o}$$ ……………. (2)

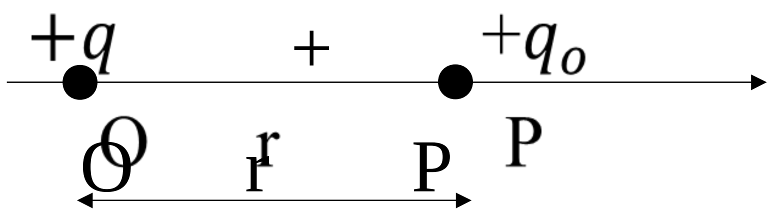
Where q_o is a point charge placed near a charge q.

F is the electrostatic force acting on the point charge.

⇒ The force exerted by an electric field on a charge is $F = q_o E$. (3)

The electric field intensity is a vector quantity and it is measured in N C^{-1}.

Electric Field Intensity due to a Point Charge



Let q be the point charge placed at point O in the air. A test charge q_o is placed at P separated by a distance r from O.

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Using the expression of Coulomb's law, the force between q_o and q is

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

At a point P, the electric field is expressed as

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$$E = \frac{F}{q_o} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \quad .... (4)$$

Example

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Calculate the magnitude of a point charge chosen so that electric field 30.0 cm away has the magnitude 5.0 N C^{-1}

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Solution

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= $$E = \frac{F}{q_o} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = \frac{Kq}{r^2}$$

= $$\therefore \quad q = \frac{Er^2}{K} = \frac{5 \times (0.3)^2}{9 \times 10^9}$$

C $$= 5 \times 10^{-11}\,\text{C}$$

Electric Potential

•

The Electric Potential, V (volt) at any point in an electric field is defined as the amount of work done, W (Joules) expended in bringing a unit positive charge Q (Coulomb) to that point against the electric field.

Mathematically,

Electric potential, $V = \frac{W}{Q}$ (5)

(6) $\Rightarrow W = QV$ (6)

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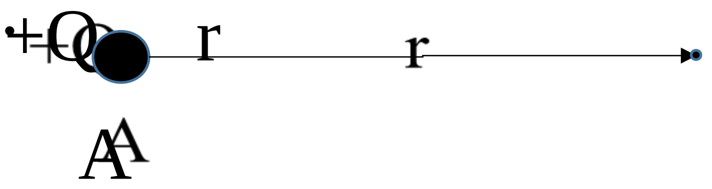
Mathematically,

Electric potential, (5)

Electric Potential at a point



The work done in taking 1 C of positive charge q from infinity to point A which is at a distance r from the charge +Q is expressed as

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

Where, the force at point A due to charge +Q is

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$$F = \frac{q}{4\pi\varepsilon_o r^2}$$

$$\Longrightarrow W = \int_{\infty}^{r} \frac{-q}{4\pi\varepsilon_o r^2}\, dr \qquad (7)$$

(7)

Applying equation (5), we obtain

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$$V = \int_{\infty}^{r} \frac{-q}{4\pi\varepsilon_o r^2}\, dr = \frac{q}{4\pi\varepsilon_o} \int_{\infty}^{r} \frac{dr}{r^2}$$

$$V = \frac{q}{4\pi\varepsilon_o}\left[\frac{1}{r} - \frac{1}{\infty}\right]$$

Hence,

Hence,

$$V = \frac{q}{4\pi\varepsilon_o r} \qquad Or\ V = \frac{Kq}{r} \qquad (8)$$

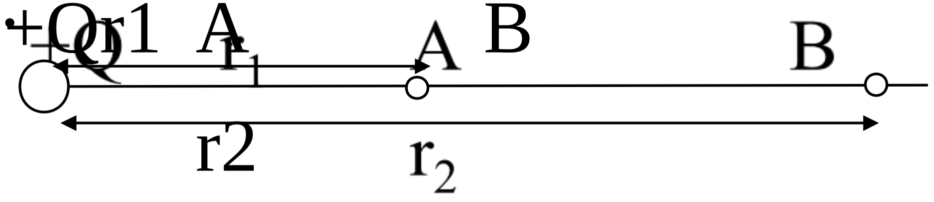
(8)

Where

Where $K = \frac{1}{4\pi\varepsilon_o}$

Potential Difference Between Two Points

+Qr1 A B



r2

VA = The electric potential at point A, =

V_A = The electric potential at point A, = $\frac{Q}{4\pi\varepsilon_o r_1}$

VB = The electric potential at point B, =

V_B = The electric potential at point B, = $\frac{Q}{4\pi\varepsilon_o r_2}$

- = The potential difference between points A and B

V_B - V_A = The potential difference between points A and B

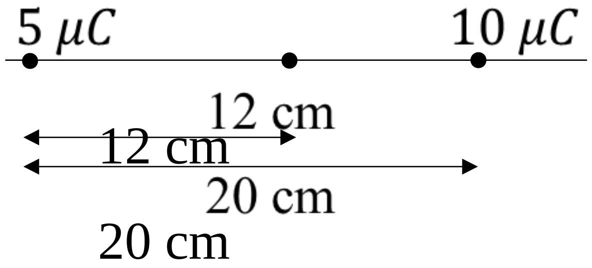
- = (9)

$$V_B - V_A = \frac{q}{4\pi\varepsilon_o}\left[\frac{1}{r_2} - \frac{1}{r_1}\right] \qquad (9)$$

Worked Example

Charges 5 μC and 10 μC are kept 20 cm apart. Calculate the work done in bringing them 8 cm closer so that they are 12 cm away from each other.

Solution



If the 5 μC is fixed in position, then the potential difference between 12 cm and 20 cm from the 5 μC is given by

$$V = V_B - V_A = \frac{q}{4\pi\varepsilon_o}\left[\frac{1}{r_2} - \frac{1}{r_1}\right]$$

$$V = \frac{5 \times 10^{-6}}{4\pi \times 8.85 \times 10^{-12}}\left[\frac{1}{0.12} - \frac{1}{0.2}\right]$$

$$V = 4500\ (3.33) = 1.5 \times 10^4\ V$$

The work done in taking the 10 μC charge from 20 cm to a point 12 cm from the 5 μC charge is

$$W = QV = 10 \times 10^{-6} \times 1.5 \times 10^4$$

$$W = 0.15\ J$$

Potential Gradient

Potential gradient refers to the rate of change of potential with distance. It is denoted by ***g*** and expressed as

$$g = \frac{dV}{dx} \qquad (10)$$

Where dV = change in potential between the two points

dx = distance apart

the unit of potential gradient is volt per meter (Vm^{-1})

The electric field intensity is related to the potential gradient, g by the expression

$$E = -\frac{dV}{dx} \qquad (11)$$

This implies that the electric field intensity is equal to the negative of the potential gradient.

$$E = \frac{V}{x} \qquad (12)$$

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