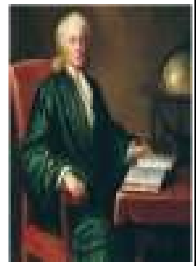
TOPIC 17: ELECTRIC FIELD

- 17.1 Force between point charges
- 17.2 Electric field of a point charge
- 17.3 Electric potential

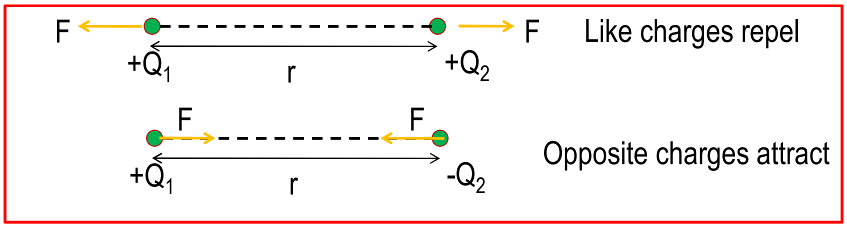
Electric field

- A region where an electric force will act on a charge that placed in the region.
- Electric field is produced by a charge or an electric potential difference across two conductors. Hence, an electric field can exists in the space surrounding the charge.

Coulomb's Law



- In 1785, Charles Coulomb proposed a law that describes the force that 1 charged particles exerts on another.
- Coulomb Law says that: the magnitude of the force between 2 point charges (Q_1 and Q_2) which are a distance, r apart is directly proportional to the product of the charges and inversely proportional to the square of their distance apart.
- Consider 2 stationary point charges Q_1 and Q_2 in vacuum separated by distance r. An electric force of magnitude F acts on each charge.



Coulomb's Law

- Mathematically, Coulomb's law can be expressed as:

$$F \propto \frac{Q_1 Q_2}{r^2} \quad \Rightarrow \quad F = k\frac{Q_1 Q_2}{r^2}$$

- Where k is a constant of proportionality

$$k = \frac{1}{4\pi\epsilon_0}$$

ε_0 = permittivity of free space, (8.85×10^{-12} Fm^{-1})
**permittivity is a measure of how easy it is for an electric field to pass through space.*

- Hence, **$k = 8.99 \times 10^9$ Nm^2C^{-2}**
- This equation is known as Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Example 1

- What is the type and magnitude of the Coulomb force between two point charges -2 μC and +5 μC having a distance of 0.03 m apart in vacuum?

Example 2

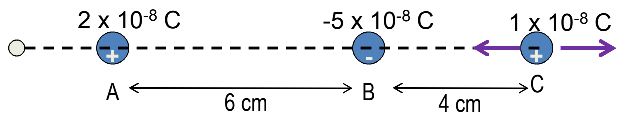
- Find the force between

(a) A proton and an electron in a hydrogen atom if their separation is 5.3×10^{-11} m

(b) A charge of 7 nC and a charge of 20 nC placed 2 cm apart in a vacuum

(c) The Earth, with a charge of 2 MC, at a distance of 1.5×10^{11} m from the Sun, with a charge of 6000 MC

Example 3



- (a) Calculate the force on the charge C due to A and B

Example 4

- 2 protons in a nucleus of an atom are separated by a distance of 10^{-15} m. Calculate the

  i.) electrostatic force of repulsion between them

  ii.) gravitational force of attraction between them

  iii.) Is the gravitational force enough to balance the repulsive electric force?

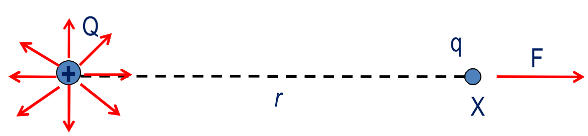
  iv.) What does this suggest to you about the forces between protons within a nucleus?

Electric field strength due to a point charge

- **Electric field strength** at a point in an electric field is the **force per unit positive charge** exerted by the field at that point.
- $E = \frac{F}{q}$ Unit: NC^{-1} or Vm^{-1}
- Is a vector quantity.
- Its direction is the same as the direction of the electric field lines as and the direction of electric force acting on a positive charge in the field.

Electric field strength of an electric field produced by an isolated point charge

- An isolated positive charge Q in free space produces an electric field in which the direction of E is radially outwards from centre of +Q.
- Suppose another positive charge q is placed at a point X in the electric field produced by charge Q. This point X is at distance *r* from Q.



- We are going to determine an expression for the electric field strength E at X

$E = F / q$; $F = Qq / 4\pi\varepsilon_o r^2$

$E = (Qq / 4\pi\varepsilon_o r^2)(1/q) \Rightarrow \boxed{E = Q / 4\pi\varepsilon_o r^2}$

Calculating Electric Force & Electric Field strength due to a number of point charges

First step:

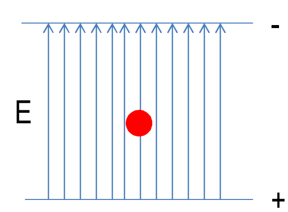
- The magnitudes of the individual forces / electric field strength can be determined through Coulomb's law calculations. The direction of the individual forces / electric field strength are determined by applying the rules of charge interactions / direction of electric field lines.

Second step:

- Once the magnitude and direction of the number of force / electric field strength vectors are known, the number of vectors can be added using rules of vector addition in order to determine the net electric force / electric field strength.

Example 5

- A particle of mass 0.50 g and carrying a charge +5μC is held in a uniform electric field of strength 2.0 kNC^{-1}. If the particle is released from rest, determine the acceleration of the particle



Example 6

- The magnitude of the electric field strength at a point 10 cm from a point charge is 200k NC^{-1}. Determine the field strength at a point 20 cm from the point charge.

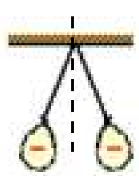
Example 7

- Two 1.1-gram balloons are suspended from 2.0-meter long strings and hung from the ceiling. They are then rubbed ten times with animal fur to impart an identical charge Q to each balloon. The balloons repel each other and each string is observed to make an angle of 15 degrees with the vertical. Determine the

  i.) electric force of repulsion,

  ii.) charge on each balloon (assumed to be identical), and

  iii.) quantity of electrons transferred to each balloon as a result of 10 rubs with animal fur.



Example 8

- A positively charged object with a charge of +85 nC is being used to balance the downward force of gravity on a 1.8-gram balloon that has a charge of -63 nC. How high above the balloon must the object be held in order to balance the balloon?

Example 9

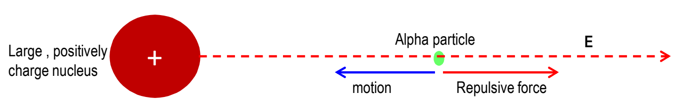
- Two 1.2-gram balloons are suspended from light strings attached to the ceiling at the same point. The net charge on **EACH** balloon is - 540 nC. The balloons are distanced 68.2 cm apart when at equilibrium. Determine the length of the string.

Example 10

- Three charges are placed along the X-axis. Charge A is a +18 nC charge placed at the origin. Charge B is a -27 nC charge placed at the 60 cm location. Where along the axis (at what x-coordinate?) must positively charged C be placed in order to be at equilibrium?

Electric Potential & Electric Potential Energy

- Let's begin by considering an alpha particle approaching a nucleus.



- An electric force acts on a charge situated in an electric field.
- If the charge is moved over a distance against this force, work is done against the electric force and thus the system gains electric potential energy.
- The amount of potential energy gained is equal to the work done in moving the charge.
- In the case show above, points close to the nucleus are at a higher electric potential energy than points further away.
- The zero of electric potential energy is the potential energy at an infinite distance from an electric charge.

Electric Potential & Electric Potential Energy

- So the **electric potential energy, U** of a test charge at any point is defined as **the work done in bringing the charge from infinity to that point.**

$U = W = Fr = (Qq/\ 4\pi\varepsilon_o r^2)(r)$
$\mathbf{U = Qq / 4\pi\varepsilon_o r}$; unit = Joule

- Remember, when work is done on system → system gain P.E.
- On the other hand, if work is done by system → system loses PE.

Electric Potential & Electric Potential Energy

- Meanwhile the **electric potential** at any point in an electric field is defined as **the work done in bringing unit charge from infinity to that point.**

- If W is the work done in moving a small positive test charge, q from infinity to that point, the potential V of that point is given by:

$V = W / q$
$V = Fr / q = (Qq / 4\pi\varepsilon_o r^2)(r/q)$;
$\mathbf{V = Q / 4\pi\varepsilon_o r}$; unit = V / JC^{-1}

Electric potential is a scalar quantity which can be added directly when more than 1 field is involved.

- The amount of energy which an electron acquires when it accelerates through a p.d. of 1 V is:

Energy acquired = work done = qV
Energy acquired = $(1.6 \times 10^{-19})(1) = 1.6 \times 10^{-19}$ J
This value is also called 1 eV. (1 electronvolt)

Example 11

- Electrons in a cathode ray tube leave the cathode at a potential of -9000V and are accelerated to an anode at a potential of -200V. For an electron in this tube calculate

  i.) the gain in electrical potential

  ii.) the loss in potential energy

  iii.) the gain in kinetic energy

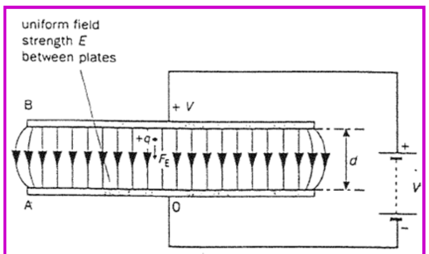
  iv.) the speed on reaching the anode

Relationship between Potential Gradient & Electric field Strength

- Potential gradient at a point in a field is the change of potential per unit distance at that point. Unit is Vm^{-1}.
- The electric field strength is the same as the potential gradient but with an opposite sign. $E = \frac{-dV}{dx}$ $\boxed{\text{Electric Field Strength = - Potential Gradient (at any point)}}$

- Between 2 oppositely charged parallel plates, the potential changes steadily from 1 plate to another.
- The change of potential per unit distance along the line between the plates is constant.
- This is an example of constant potential gradient.

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



Moving a charge in the uniform field between two charged plates

Comparison between Electric n Gravitational Field

CATEGORY	ELECTRIC FIELD	GAVITATIONAL FIELD
Origin of force	Due to charge interaction	Due to mass interaction
Nature of force	Attractive (unlike charge) Repulsive (like charge)	Only attractive
Constant of proportionality	Depends on the medium	Same for all medium
Force equation	$F_E = kQq / r^2$ $F = qE$	$F_G = GMm / r^2$ $F = mg$
Field Strength	$E = kQ / r^2$	$g = GM / r^2$
Potential	$V = kQ / r$	$\Phi = - GM / r$
Potential Energy	$U_E = kQq / r$	$U_G = - GMm / r$