# RATU NAVULA COLLEGE Y12 PHYSICS HOME LEARNING KIT 6

**STRAND 5 : ELECTRICITY**

**S/S 5.1 ELECTROSTATICS**

**LESSON 87 LO: study and use Coulomb's Law and electrostatic force.**

## ELECTROSTATICS

- is the study of electric charges, forces and fields.
- Symbol of electric charge is 'q'
- Unit for charge is Coulumb (C)
- 1 C = 6.25 X $10^{-19}$C and 1 electron has a charge of 1.60 X $10^{-19}$ C.

## Coulombs law

- States that two charged objects attract each other with a force that is proportional to the charge on the object and is inversely proportional to the square of the distance between them.

$$F \quad \alpha \quad \frac{q_1 q_2}{r^2}$$

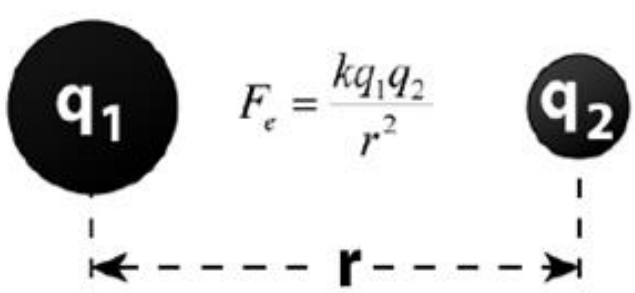
| | | |
|---|---|---|
| where | $Q_1$ | is the charge on the one point-like object(C), |
| | $Q_2$ | is the charge on the second,(C), |
| | r | is the distance between the two (m) and |
| | F | is the magnitude of the electrostatic force between two point-like charges (N). |

To make an equation out of this proportionality, a quantity called the **electrostatic constant, *k*** is inserted.

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

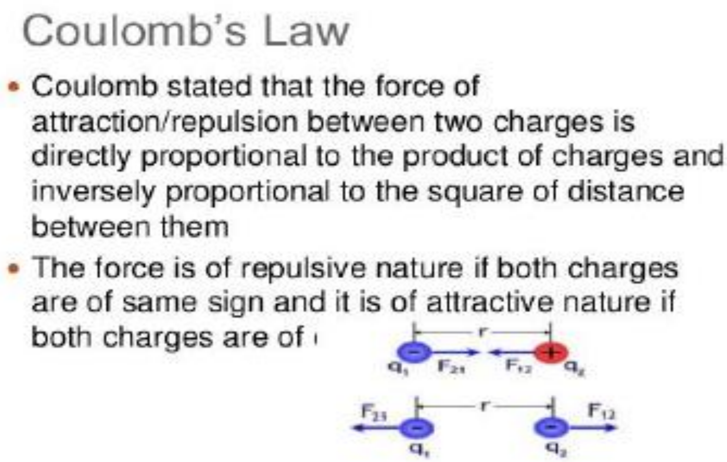
The magnitude of Coulomb's law can now be written as an equation:

$$\text{Electrostatic force} = \frac{(K_{electrostatics})(Charge1)(Charge2)}{(distance)^2}$$




$$F_e = \frac{kq_1q_2}{r^2}$$

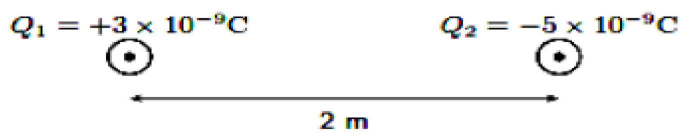
http://www.aplusphysics.com/courses/honors/estat/Coulomb.html




EXAMPLE

Two point-like charges carrying charges of +3 × $10^{-9}$ C and -5 × $10^{-9}$ C are 2 m apart. Determine the magnitude of the force between them and state whether it is attractive or repulsive.

Given: $q_1 = +3 \times 10^{-9}$ C
$q_2 = -5 \times 10^{-9}$ C
r = 2 m




Using Coulomb's Law we have

$$F = \frac{Kq_1q_2}{r^2} = \frac{(9\times10^9\, Nm^2C^{-2})(3\times10^{-9}\,C)(5\times10^{-9}\,C)}{(2m)^2} = \underline{3.37\times10^{-8}\,N}$$

Thus, the magnitude of the force is $3.37\times10^{-8}\,N$. However since both point charges have opposite signs, the force will be attractive.

EXAMPLE

Determine the electrostatic force and gravitational force between two electrons $10^{-10}$ m apart (i.e. the forces felt inside an atom).

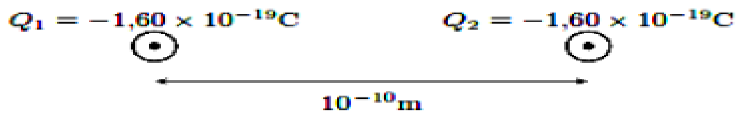
*Soln:* We are required to calculate the electrostatic and gravitational forces between two electrons, a given distance apart.
We can use:

$F_e = \frac{Kq_1q_2}{r^2}$ to calculate the electrostatic force and $F_g = \frac{Gm_1m_2}{r^2}$ to calculate the gravitational force.

Given: $q_1 = q_2 = 1.6 \times 10^{-19}$ C (charge of an electron)
$m_1 = m_2 = 9.1 \times 10^{-31}$ kg (mass of an electron)
$r = 1 \times 10^{-10}$ m

$K = 9 \times 10^9\ Nm^2C^{-2}$
$G = 6.67 \times 10^{-11}\ Nm^2kg^{-2}$

We can draw a diagram of the situation.




**Electrostatic Force**:

$$F_e = \frac{Kq_1q_2}{r^2} = \frac{(9\times10^9\ Nm^2C^{-2})(1.6\times10^{-19}C)(1.6\times10^{-19}C)}{(1\times10^{-10}m)^2} = \underline{2.3\times10^{-8}N}$$

Hence the magnitude of the electrostatic force between the electrons is $\underline{2.3\times10^{-8}N}$. Since electrons carry the same charge, the force is repulsive.

## Gravitational Force:

$$F_g = \frac{Gm_1m_2}{r^2} = \frac{(6.67\times10^{-11}Nm^2kg^{-2})(9.1\times10^{-31}kg)(9.1\times10^{-31}kg)}{(1\times10m)^2} = \underline{5.54\times10^{-51}N}$$

## Electrical vs. Gravitational Forces

$$F_e = \frac{k \cdot q_1 \cdot q_2}{r^2}$$

$k = 8.99 \times 10^9\ N{\cdot}m^2/C^2$

$$F_e = \frac{G \cdot m_1 \cdot m_2}{r^2}$$

$G = 6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2$

**The similarities:**

- Both equations have same **form**.
- Both equations show an **inverse square** relationship between force and separation distance.
- both equations show that the force is **proportional** to the **product** of the **quantity that causes the force**.
- Both electrical force and gravitational force are **non-contact** forces.

**The difference:**

- Coulomb's law constant (**k**) is significantly **greater** than Newton's universal gravitation constant (G). Subsequently the force between charges – **electric force** - are significantly **stronger** than the force between masses – gravitational force.
- **Gravitational** forces are only **attractive**; **electrical** forces can be either **attractive** or **repulsive**.

**ACTIVITY**

**2014**

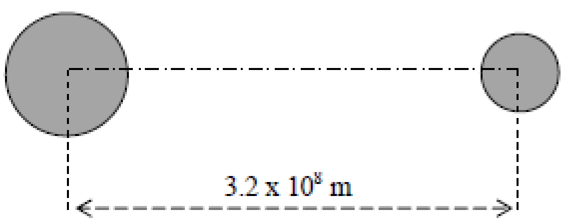
The fundamental unit of charge is

A. a proton.
B. a neutron.
C. an electron.
D. the Coulomb.

**2013**

1.

The diagram given below shows two masses $7.35 \times 10^{21}$ kg and $5.98 \times 10^{24}$ kg separated by a distance of $3.2 \times 10^{8}$ m.




(i) Calculate the gravitational force between the two masses.

(ii) By what factor will the gravitational force change if both the masses are doubled and the distance between the two masses is reduced to half of its original value?

**LESSON 88 LO: calculate electric field between one or two point charge**

## ELECTRIC FIELD

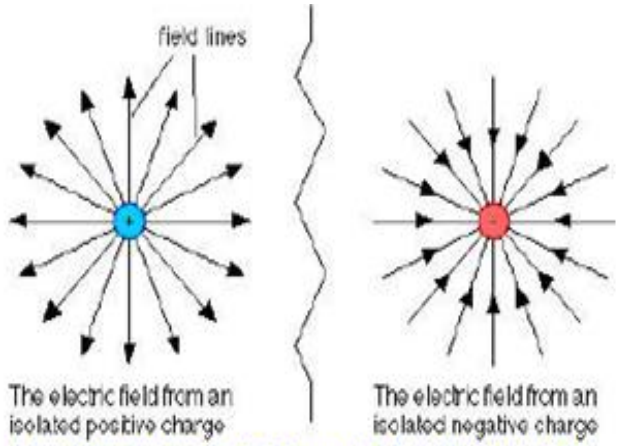
- Is an area of influence around a charged object.
- Magnitude of the field is proportional to the amount of electrical force exerted on a positive test charge placed at a given point in the field.
- Unit for electric field is newton per coulomb (N/C)

$$E = \frac{F}{q}$$

Where E = Electric Field (N/C)
F = Electrostatic Force (N)
q = Test Charge (C)

## Field near a Point Charge

- A point charge has around it a radical electric field.
- If the charge is positive the field is directed away from the charge and if the charge id negative, the field is directed towards the charge.




http://physics.appstate.edu/laboratory/quick-guides/electric-fields

For a point charge (or other spherical charge distribution), the magnitude of the electric field can be written as

$$E = \frac{F}{q_0} = \frac{kq_0 q}{q_0 r^2} = \frac{kq}{r^2}$$

Where $q$ is the charge on the surface of the object (C), and
$r$ is the distance between the centre of the charged object and a small positive test charge, $q_0$, placed in the field (m).

EXAMPLE

Shirley pulls her wool sweater over her head, which charges her body as the sweater rubs against her cotton shirt.

(a) What is the electric field at a location where a $1.60 \times 10^{-19}$ C - piece of lint experiences a force of $3.2 \times 10^{-9}$ N as it floats near Shirley?

(b) What will happen if Shirley now touches a conductor such as a door knob?

*Soln:* **a.** $E = \frac{F}{Q} = \frac{3.2 \times 10^{-9} N}{1.6 \times 10^{-19} C}$ = **$2 \times 10^{10}$ N/C**

**b.** She will reduce her charge in a process called **grounding,** in which excess electrons flow from her body into the ground and spread evenly over the surface of Earth.

EXAMPLE

A fly accumulates $3.0 \times 10^{-10}$C of positive charge as it flies through the air. What is the magnitude and direction of the electric field at a location 2.0 cm away from the fly?

$$E = \frac{kq}{r^2} = \frac{(9.0\times10^{9}\,Nm^2C^{-2})(3.0\times10^{-10}\,C)}{(0.020m)^2} \quad = \quad \textbf{6800 N/C away from the fly.}$$

EXAMPLE

Two charges of $Q_1$ = +3 nC($3 \times 10^{9}$C) and $Q_2$ = -4 nC($-4 \times 10^{9}$C) are separated by a distance of 40 cm. What is the electric field strength at a point that is 10 cm from $Q_1$ and 30 cm from $Q_2$? The point lies between $Q_1$ and $Q_2$.


Given: $Q_1 = 3 \times 10^{-9}$C
$Q_2 = -4 \times 10^{-9}$C
$R_1$ = 0.1 m
$R_2$ = 0.3 m

*Step 1*: first solve for $Q_1$: $$E = \frac{kq}{r^2} = \frac{(9.0\times10^{9}\,Nm^2C^{-2})(3.0\times10^{-9}\,C)}{(0.10m)^2} = 2700N/C$$

*Step2*: solve for $Q_2$: $$E = \frac{kq}{r^2} = \frac{(9.0\times10^{9}\,Nm^2C^{-2})(4.0\times10^{-9}\,C)}{(0.30m)^2} = 400N/C$$

*Step 2*: We need to add the two electric field because both are in the same direction. The field is away from $Q_1$ and towards $Q_2$. Therefore,

$E_{TOTAL}$ = 2700 N/C + 400 N/C = **3100 N/C**

ACTIVITY

2009

An electric charge in uniform motion produces

A. an electric field only.
B. a magnetic field only.
C. both electric and magnetic fields.
D. neither electric nor magnetic field.

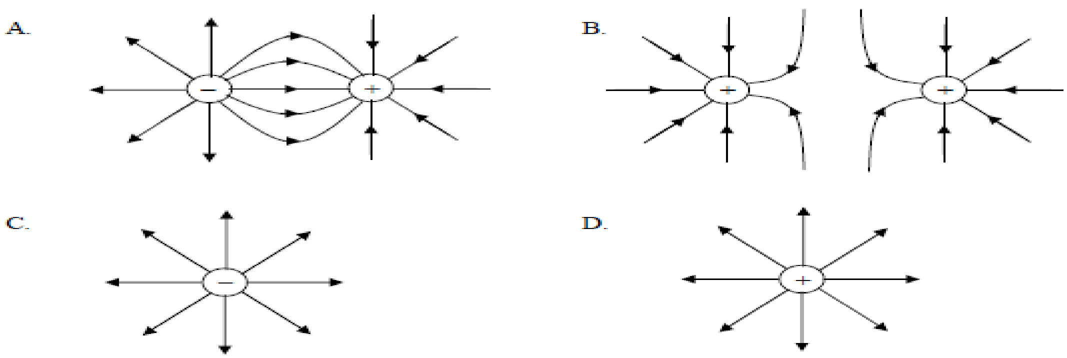
2015

What law describes the force between two stationary electrically charged objects?

A. Ohms Law
B. Faradays Law
C. Newton's Law
D. Coulombs Law

2014

Which of the following electric field line patterns is correct?




**LESSON 89 LO: use conservation of law of energy onto charge in electric field**

**Electric Potential Energy**

- The electric potential energy of a charge q at distance r is given by

$$E_p = \frac{kQ_1Q_2}{r}$$

where k is Coulomb's constant.

**Electric Potential Difference**

- Is the work done to move a positive test charge from one location to another.
- Unit for potential difference is Volts (V) which is same as joule per coulomb (J/C)

$$\text{Potential Difference} = \frac{Work}{TestCharge} \quad \text{or} \quad V = \frac{W}{q}$$

EXAMPLE

What is the potential difference between two point in an electric field if it takes 600 J of energy to move a charge of 2 C between these two points.

Given: W = 600 J

Q = 2 C

Find: Potential difference, V:

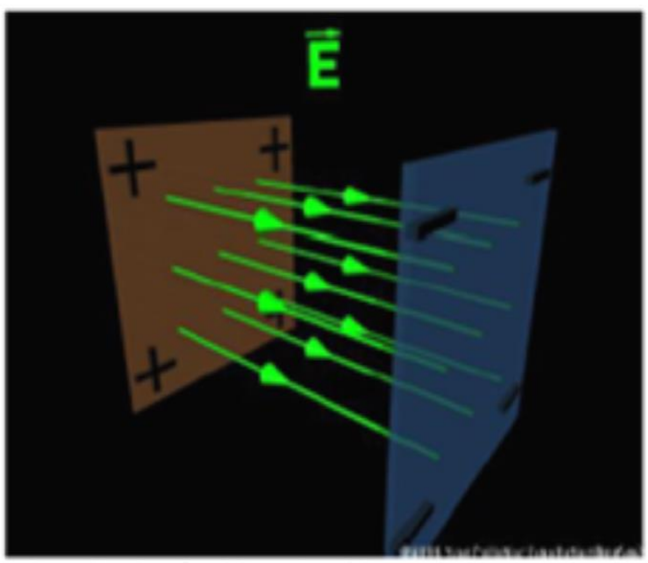
We use $V = \frac{W}{Q} = \frac{600J}{2C}$ $V = 300V$

EXAMPLE

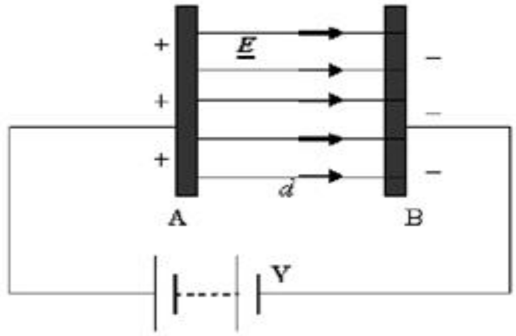
An **electron** in Akeneta's TV is accelerated toward the screen across a potential difference of 22 000 V. How much kinetic energy does the electron lose when it strikes the TV screen?

$$V = \frac{W}{Q} \Longrightarrow W = VQ = (22000V)(1.6\times10^{-19}C) = 3.5\times10^{-15}J$$

## LESSON 90 LO: STUDY FIELD BETWEEN TWO CHARGED PARALLEL PLATES




http://web.ncf.ca/ch865/englishdescr/EFld2Plates.html




The work done to move a charge, *q*, a distance *d* between the plates is: $W = F \bullet d$

Since $F = Eq$ , $\therefore$ $W = Eqd$ (1)

Also Voltage (potential difference), *V*, is $V = \dfrac{W}{q}$ ,

Therefore $W = Vq$ (2)

Equating equations (1) and (2) $Vq = Eqd$ ,

Thus, $$V = Ed$$

Where :
V = potential difference (V)
E = electric field strength between the plates $\left(\frac{N}{C} = \frac{V}{m}\right)$
*d* = separation distance of the plates (*m*)

Also Voltage (potential difference), *V*, is $V = \dfrac{W}{q}$ ,

Therefore $W = Vq$ (2)

Equating equations (1) and (2) $Vq = Eqd$ ,

Thus, $$V = Ed$$

Where :
V = potential difference (V)
E = electric field strength between the plates $\left(\frac{N}{C} = \frac{V}{m}\right)$
*d* = separation distance of the plates (*m*)

EXAMPLE

Two oppositely charged plates are separated a distance of 3 cm and attached to a potential difference of 12 V.

(a) Calculate the electric field strength between the plates.

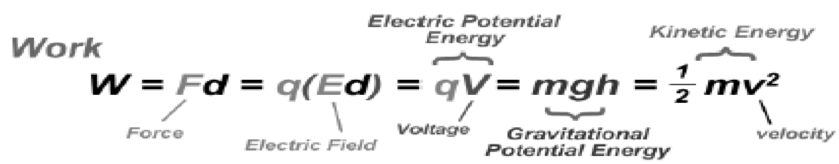
(b) What is the force on an electron in the plates? (Charge of an electron = $1.06 \times 10^{-19}$ C)

*Solution:* (a) $E = \dfrac{V}{d} = \dfrac{12V}{0.3m} = \underline{400 \ \dfrac{N}{C}}$

(b) $F = Eq = (400 \text{ N/C})(1.0 \times 10^{-19} \text{ C}) = \underline{6.4 \times 10^{-17} \text{ N}}$

**Points to Note:**

- If the electric field E is uniform, the force on a charge is independent of the position of the charge in the field. ( F = Eq )
- Electric field strength E is given by: $E = \dfrac{V}{d}$, units $\left(\dfrac{N}{C} = \dfrac{V}{m}\right)$
- Work done on a charge *q* is: ***W = Eqd***
- The work done on a charge becomes the $E_K$ (kinetic energy ) of the charge;




http://sdsu-physics.org/physics180/physics180B/Chapters/electric_potential.htm

EXAMPLE

A potential difference of 100 V is connected to two parallel plates. Calculate the velocity with which an **electron** leaving the negative plate strikes the opposite plate.

(Charge, $q = 1.6 \times 10^{-19}$ C, mass, $m = 9.11 \times 10^{-31}$ kg)

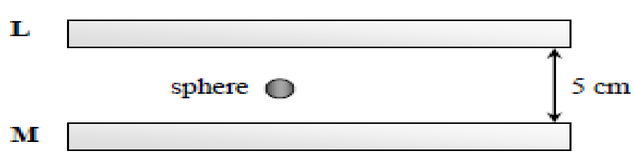
**Work done = gain in $E_K$** : $Eqd = \frac{1}{2} mv^2$, $Vq = \frac{1}{2} mv^2$

$(100V)(1.6\times10^{-19}C) = \frac{1}{2}(9.11\times10^{-31}kg)v^2$

$\underline{v = 5.96 \times 10^{6} \text{ m/s}}$

## ACTIVITY
## 2017

A tiny sphere is balanced between two horizontally charged plates; **L** and **M**, which are 5 cm apart. The gravitational force on the sphere is $5.2 \times 10^{-14}$ N. The charge on the sphere is $-3.2 \times 10^{-19}$ C.

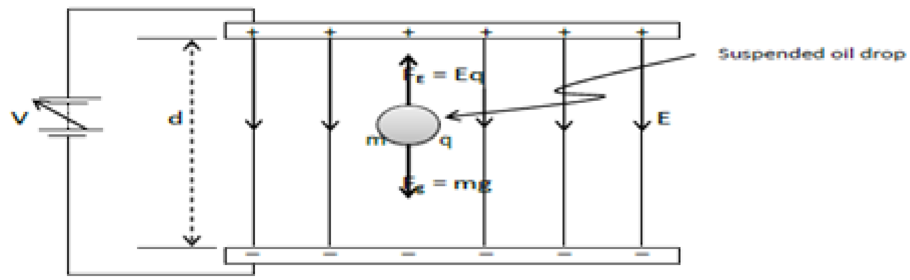



(i) Calculate the size and direction of the electrical force on the sphere.

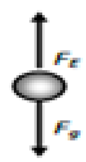
(ii) Determine the value of electric field strength between the plates.

## LESSON 91 LO: Study MILIKANS OIL DROP EXPERIMENT

- A pair of parallel plates were set up with a variable voltage
- Oil drops were exposed to X rays and they dropped through the hole between the plates




- The charge experiences gravitational and electrical forces as shown




$F_E = Eq$ , $F_g = mg$

- When an oil drop becomes stationary, the gravitational and electrical forces are equal.

$$Eq = mg$$

$$\frac{Vq}{d} = mg \quad , \quad q = \frac{mgd}{V}$$ (*m, d and V are measurable quantities.*)

- Milikan discovered that only whole number values of charge were found. This means that charge occurs in discrete values. That is multiples of the smallest charge.

$$\boxed{Q = ne^-}$$ *unit* : Coulomb (C)

Where : $n$ = number ( n = 1,2,3,.... )
$e^-$ = $1.6 \times 10^{-19}$ C

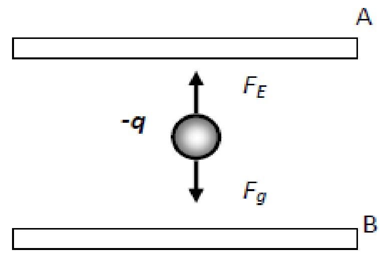
## THE ELECTRON VOLT

- An electron volt (eV) is the energy required by an electron in moving through a potential difference of 1 Volt.

EXAMPLE

In a Millikan experiment set – up, an oil drop of mass 2.05 x $10^{-12}$ kg is suspended between plates A and B. The plates are at a separation of 5 cm and at a potential difference of 500 V.

(a) What is the polarity of A?
(b) Calculate the electric field strength, E.
(c) What is the charge on the oil drop?




Solution:

(a) The polarity of A should be **positive**. (+)

(b) $E = \frac{V}{d} = \frac{500V}{0.05m} = 10\ 000\ NC^{-1}$

(c) $F_E = F_g$ , $Eq = mg$ , $q = \frac{mg}{E} = \frac{(2.05 \times 10^{-12} kg)(10 m/s^2)}{10000 N/C}$

$= 2.05 \times 10^{-15}$ C

***Note***

1. For charges being accelerated between a pair of parallel plates, the expression for velocity as the charge reaches the opposite plate is given by:

   $Vq = ½ mv^2$ , $v = \sqrt{\frac{2Vq}{m}}$

2. The expression for acceleration is given by:

   Equating $F = ma$, and $F = Eq$ , $a = \frac{Eq}{m}$

   [ ***V*** = potential difference (V), and ***v*** = velocity (m/s) ]

**THE ELECTRON VOLT**

An electron volt (eV) is the energy acquired by an electron in moving through a Potential Difference of 1 volt.

$$1eV = 1.6 \times 10^{-19} J$$

**ACTIVITY**

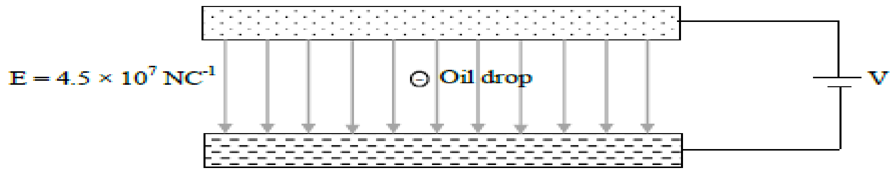
**2018**

**1.**

Energy per unit positive charge is commonly known as

**2.**

In Millikan's oil drop experiment a negatively charged droplet of oil of mass $3 \times 10^{-5}$ kg is placed between two oppositely charged plates. The oil drop becomes stationary between the plates when an electric field strength of $4.5 \times 10^{7}$ $NC^{-1}$ is applied.




(i) Calculate the charge of the oil drop in this experiment.

(ii) State the conclusion of Millikan's oil drop experiment.

2019

Milikan's oil-drop experiment was designed to measure

A. mass of an electron.
B. speed of an electron.
C. charge of an electron.
D. the charge to mass ratio for an electron.

## S/S 5.2 CURRENT ELECTRICITY

## LESSON 92 LO: define terms related to electricity

## CURRENT AND RESISTANCE

- **Current** is the amount of charge that passes through an area in a given amount of time.
- Unit for current is Ampere (A) which equals one coulomb per second (C/s)

$$Current = \frac{Charge}{Time} \quad \text{or} \quad I = \frac{\Delta q}{\Delta t}$$

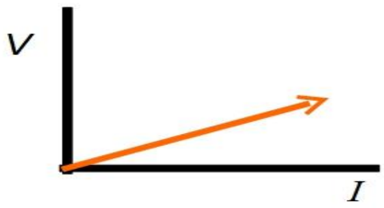
- **Resistance** is an opposition of flow of current.
- Unit for resistance is ohms which is one volt per amp (V/A)

$$Potential Difference = Current \times Resistance$$
$$V = IR$$

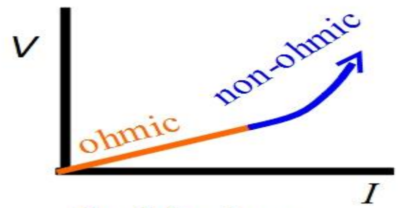
## Ohmic vs. Nonohmic Resistors

If Ohm's law were always true, then as $V$ across a resistor increases, so would $I$ through it, and their ratio, $R$ (the slope of the graph) would remain constant.

In actuality, Ohm's law holds only for currents that aren't too large. When the current is small, not much heat is produced in a real, so resistance is constant and Ohm's law holds (linear portion of graph). But large currents cause $R$ to increase (concave up part of graph).



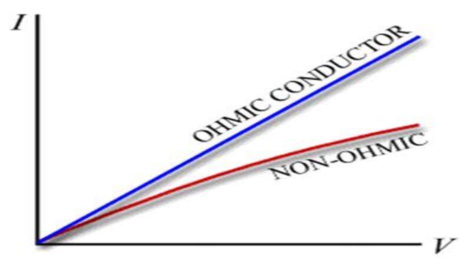

*Ohmic Resistor*




*Real Resistor*

### Summary

- Ohms law states that $V \propto I$ when T = const
- If we plot a graph of a component of v on y-axis and I on the x-axis the gradient is the resistance of the component.
- Light bulb and diode are examples of non-ohmic components




## POWER

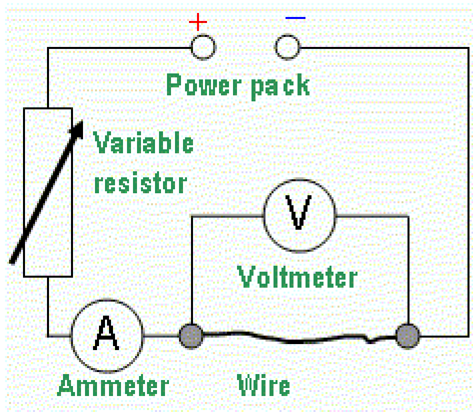
- Is the amount of work done in a given period of time
- Unit for power is watt which is one joule per second (J/s)

$$\text{Power, } P = \frac{W}{t} = \frac{\Delta q V}{\Delta t} = IV$$

Since P = IV and $R = \frac{V}{I}$, Power dissipated in a conductor can also be expressed as

$$P = I^2 R \qquad \text{or} \qquad P = \frac{V^2}{R}$$

## Basic circuit diagram setup




ACTIVITY

2014

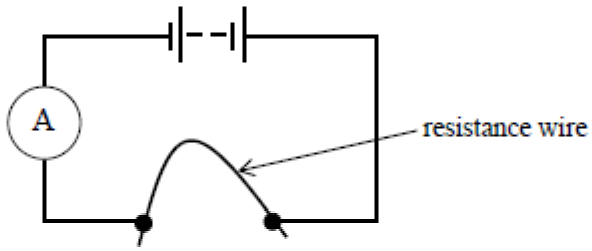
Which mathematical relationship below represents **Ohm's Law**?

A. $Q = It$
B. $F = BIl$
C. $V = Bvl$
D. $V = IR$

2013

1.

A length of resistance wire is used as a resistor in a simple circuit.




Four separate changes are made to the wire. Which change will **increase** the value of the resistance of the wire?

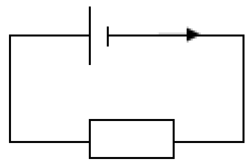
A. Its length is increased.
B. Its temperature is decreased.
C. Its cross-sectional area is increased.
D. It is covered in an insulating plastic coating.

2012

1.

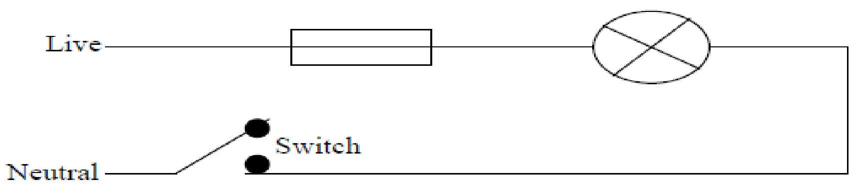
Which type of current is shown by the arrow in the electrical circuit given below?

A. conventional current
B. convectional current
C. electron current
D. proton current



2009

Shown below is a simple circuit with a lamp connected to a power supply.




(i) Identify **one** incorrect connection in the circuit. **(1 mark)**

(ii) Explain how the incorrect connection in (i) could be dangerous. **(1 mark)**