UNIT – 2 ELECTROSTATICS

Que. 01. Write a short note on electric charge.

Ans: Electric charge is the natural characteristic of all the electric materials in the world.

- We know that electrons, protons and neutrons are the fundamental particles in the structure of matter.
- Out of these particles, electrons are negatively charged and protons are positively charged and neutrons are neutral in terms of electric charge.
- All the matter in the universe is the mixture of positive and negative electric charge.
- Electron is smallest negative charge we see in whole universe.
- Two like charges repel each other while unlike charges attract each other.
- The fundamental value of electric charge is,

$$e = 1.6 \times 10^{-19}\ Coulomb$$

- This value for electrons (or negatively charged particles) can be taken as negative and positive for the protons (or positively charged particles).
- In general terms the total charge can be written as,

$$\boldsymbol{Q = ne}$$

$$Q\ (Total\ Charge) = n(no.of\ electrons) \times e(charge\ of\ electron)$$

where, $e = fundamental\ value\ of\ charge$

$$n = 0,1,2,3, \ldots \ldots \ldots (only\ integer\ values)$$

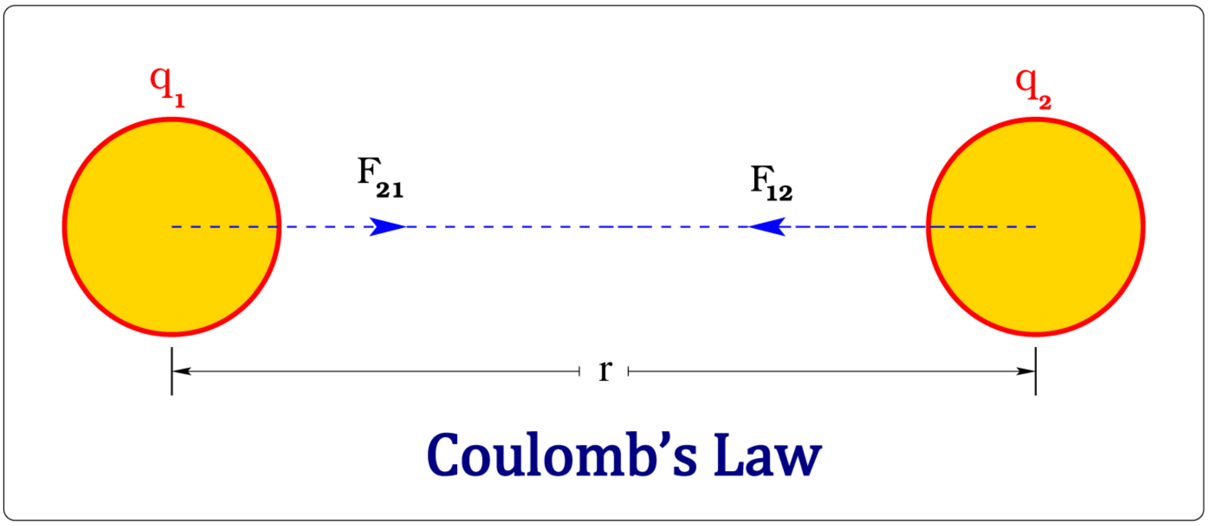
Que. 02. State Coulomb's law for the system of two charges placed in vacuum at the distance r from each other and derive an equation for the electrostatic force acting between them.

OR

Que. 02. State Inverse square law for the system of two charges placed in vacuum at the distance r from each other and derive an equation for the electrostatic force acting between them.

Ans: Coulomb's Law (the inverse squared law): The law regarding how electric charges interact with each other was introduced in 1785 by a scientist named Charles Augustine de Coulomb.

"The coulomb force exerted between two stationary point-like electric charges is proportional to the multiplication of their value



of the electric charge and inversely proportional to the square of the distance between them." The force exerted by one electric charge on the other electric charge is exerted on the line connecting those two electric charges.

The electrostatic force exerted between two electric charges is directly proportional to the multiplication of the two electric charges.

$$\vec{F} \propto q_1 \times q_2 \ldots \ldots \ldots \ldots \ldots (1)$$

More, the electrostatic force is inversely proportional to the square of the distance between the two electric charges.

$$\vec{F} \propto \frac{1}{r^2} \dots\dots\dots\dots\dots (2)$$

Combining above two facts and putting together,

$$\vec{F} \propto \frac{q_1 \times q_2}{r^2}$$

To Remove proportionality, we put constant k,

$$F = k\frac{q_1 q_2}{r^2} \dots\dots\dots\dots\dots (3)$$

Here, $k = 9 \times 10^9 \, Nm^2C^{-2}$

The value of k for vaccum is,

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

Putting this value of k in eq. (3),

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

Above eq. (4) represents the **electrostatic (or Coulomb) force** experienced by two point like charges namely q_1 and q_2.

Here, in eq. (4), the constant $\boldsymbol{\epsilon_0}$ is the permittivity of free space of vacuum.

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \, C^2N^{-1}m^{-2}$$

If we put this system of charges in medium other than vacuum then we need to use permeability of that medium ϵ should be taken into account and above eq. (4) can be rewritten as follows,

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

1. when the sign of the coulomb force for a given electric charge is negative, that force is of an attractive type.
2. when the sign of the coulomb force for a given electric charge is of the positive that force is of repulsive type.

Remember:

Sr. No.	q_1	q_2		F	Type of force
1	+	+		+	**Repulsive**
2	+	−	⇒	−	**Attractive**
3	−	+		−	**Attractive**
4	−	−		+	**Repulsive**

Que. 03. Explain the Concept of Electric field. Write its SI unit.

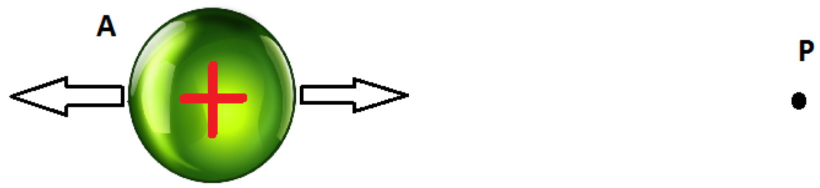
Ans: When two electric charges exert a cohesive force on each other, how does one electric charge know that there is another electric charge at a distance from it?

In order to answer this question, we need to present the Coulomb's law in a different way. Which will require a new concept called the electric field.

As shown in the figure, the two positively charged materials A and B are placed at a distance of R from each other. Suppose that $\vec{F}$ is the force experienced by B by positively electrically charged object A. Now if the object B is removed and let us call that place point P. It can be said from the figure that the positive electrically charged substance A produces an electric field before point P. Due to the electrically charged material A, even if there is no electric charge before point P, an electric field is generated at that point. Now if a reference electric charge q_0 is placed in front of the point P, it will feel the same amount of force $\vec{F}$

Reference The presence of an electrically charged object A caused q_0 by an electric charge is felt by the electric field.

Charge A exerts a force on charge B.



Removing Charge B from point P.

Electric field at point P.

"The electrical force exerted on an electrically charged object is the effect of the electric field produced by another electrically charged object."

Thus, the electric field prevailing at a point in space is the force exerted on the unit electric charge placed at that point.

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$

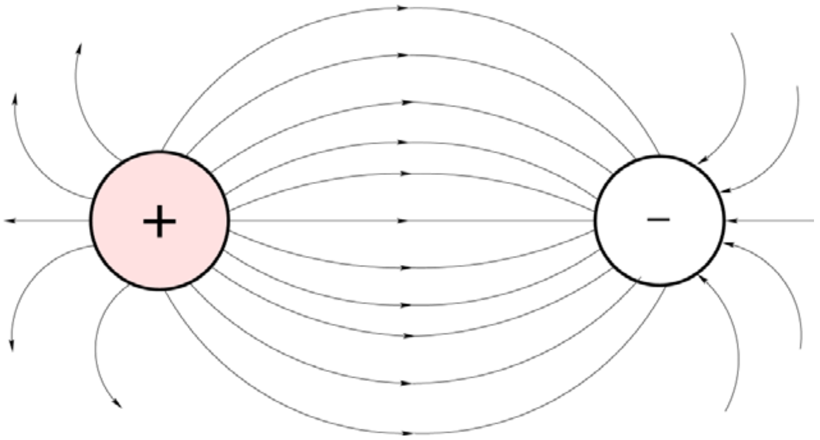
In the SI system, the unit of force is Newton and the unit of electric charge is Coulomb then unit of electric field " Volt/meter" can be written as,

$$\frac{Volt}{meter} = \frac{Newton}{Coulomb} \qquad or \qquad \frac{V}{m} = \frac{N}{C}$$

The direction of the electric field depends on the reference electric charge. For example, if the reference electric charge is positive, the force and the direction of the electric field are the same, but if the reference electric charge is negative, then the direction of force and the direction of the electric field are opposite.

Que. 04. List the properties of Electric field lines.

Ans: We know that electric charges produce an electric field in the space around them. These force lines are a type of map that speaks about the direction and value of the electric field at different places. The figure shows the field lines of positive and negative electric charges.



Properties:

1. The field lines of positive electric charges are always emerging from the the electric charge.
2. The force lines of the negative electric charges are always going inside the electric charge.
3. These field lines never begin or end in between.
4. The number of field lines emerged from a positive electric charge or the number of force lines entering the negative electric charge is always proportional to the value of corresponding electric charge.
5. If a tangent is drawn at any point on field line, that tangent shows the direction of the electric field at that point. If the electric charge is left free, it will move in the direction of this tangent in the direction of the field.
6. The two lines of the electric field never intersect each other. Because by doing so, two tangents can be drawn at that intersection point which will show two different directions of the electric field at the same point which is incompatible with the laws of physics.
7. The force lines of a uniform field are parallel to each other and at equal distance from each other (uniformly spaced).

8. The field lines of the electric field never form a closed loop, because the force lines never start with the same electric charge and end on the same electric charge.
9. The force lines of the electric field always flow from high electric potential to low electric potential.
10. The force lines of the electric field usually start as well as end from the surface of the conducting material.
11. Electric field lines enter or exit a charged surface in a normal manner.
12. The field lines are perpendicular to the surface of the charge.
13. It is not possible for electric field lines to go through a conductor. As such, inside a conductor, the electric field is always equal to zero.
14. The electric field lines are imaginary lines, a visual representation of the electric field.
15. Electric field lines are most dense around objects with the greatest amount of charge.

Que. 05. Define Electric flux and write its unit.

Ans: Flux is a Latin word meaning "to flow". Imagine a page with an area equal to $\boldsymbol{A}$ perpendicular to the uniform electric field as shown in the figure.

Now the field lines of the electric field passing through the surface having the unit area are proportional to the electric field prevailing.

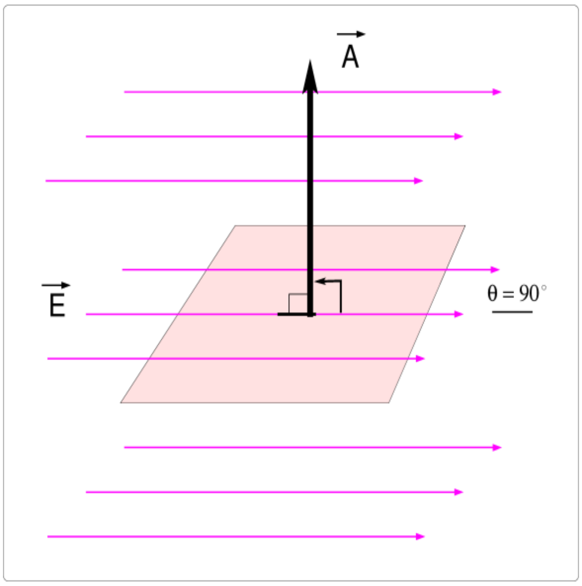
$$\frac{N}{A} \propto E$$

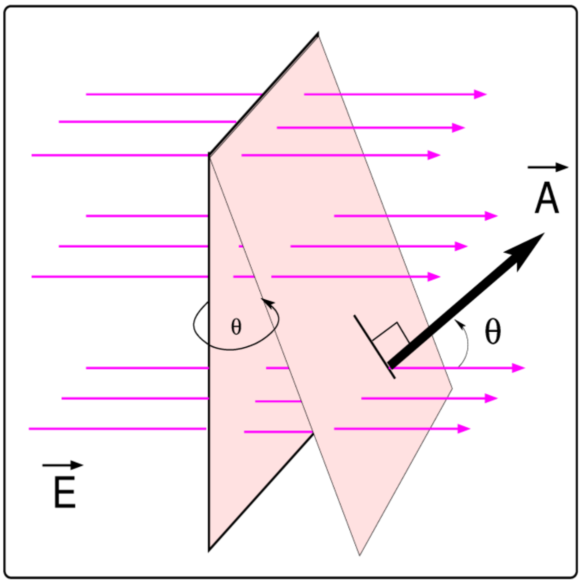
$$\therefore N \propto EA$$

Here the physical quantity EA is known as "**Flux**". Thus,

$$\phi = EA$$

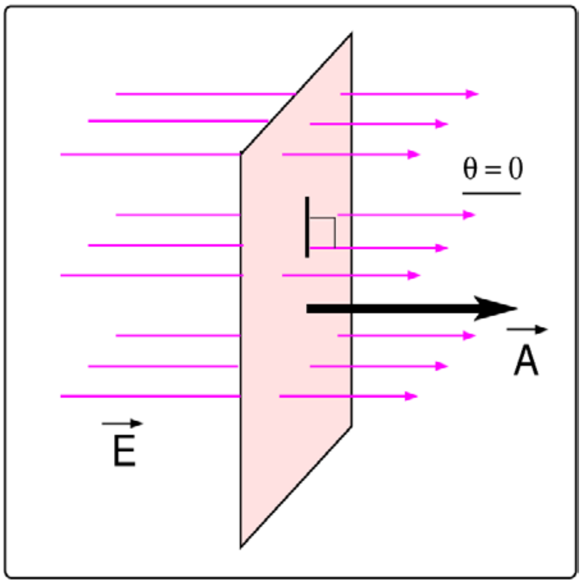
Definition: The number of force lines passing through a surface with a unit intersection at a point in the electric field is called the flux at that point.





Now if the given surface area is not perpendicular to the electric field, the number of field lines passing through the given area will decrease as shown in diagram.

If the given area is seen making an angle $\boldsymbol{\theta}$ with the electric field as shown in the figure, then two components of the area have to be considered. One of which is parallel to the electric field, and the other component is perpendicular to the electric field. The contribution of the parallel component to the flux is zero because the amount of flux enters from one edge of the page, the same amount of flux goes out of the page from the other edge. Thus only the perpendicular component of the page is considered.



$$\phi = E\ A\ cos\theta$$

$$\therefore \phi = (Ecos\theta)A$$

$$\therefore \phi = E_{\perp}\ A$$

Here it is the perpendicular component of the electric field. Writing this equation in plain form $E_{\perp}$,

$$\phi = \vec{E} \cdot \vec{A}$$

The value of the dot product of two vector product gives a scalar value. Its SI unit $N \cdot m^2/C$, which is also known as **Weber**.

$$1\ Wb = 1\ N \cdot m^2/C$$

Que. 06. Define Electrostatic Potential and explain it. Write its SI unit.

OR

Que. 06. Define Electrostatic Potential difference and explain it. Write its SI unit.

Ans: As shown in the figure, two electric plates are kept parallel to each other to produce a uniform electric field E. If a positive electric charge q_0 is placed between these two plates, this charge will experience a force.

$$F = q_0 E$$

Under the influence of this force, this electric charge moves from top to bottom. To put it simply, this positive electric charge is attracted to the lower negatively charged plate. Thus, this electric charge moves from point a to point b and covers a distance equal to d. Thus, the work done by the electric field,

$$W_{a \to b} = F \cdot d = q_0 E\ d$$

If the motion of the charged particle and the direction of the force are the same, then the value of the work done is taken to be positive.

$$\frac{W_{a \to b}}{q_0} = E \cdot d$$

$$\therefore V = E \cdot d$$

Where V is called the Electric Potential or Electric Potential Difference between two points. Its SI unit is the volt or joule/coulomb.

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

Electric potential: The work that has to be done to bring the unit positive electric charge from an infinite distance to a given point in the presence of the electric field is called the electric potential before that point.

$$\frac{W_{\infty \to a}}{q_0} = V$$

Difference in electric potential: In the presence of an electric field, the work that has to be done to bring the unit positive electric charge from a given point to a given point is called the difference in the electric potential between those two points.

Thus, the electric potential at a point in the electric field,

$$V = E * r = \frac{1}{4\pi\epsilon}\frac{Q}{r^2} * r$$

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

The electric potential difference between two points in electrical circuits is also known as voltage. In our daily life, pencil cells, button cells have an electric potential of 1.5 volts, i.e., the difference in the electric potential between its positive and negative terminal is as high as 1.5 volts. In other words, if we take the electrical potential of the negative terminal to be zero, the electron emerging from the positive terminal 1.5 volts.

Note: Here Potential / Potential difference is also known as Voltage and it is physical quantity and its unit is volt.

When potential is used b

y the means of circuit, we use term voltage. During the calculation we use the following formula.

$$V = E * r = E * d$$

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

Que. 07. What is Capacitor? Write its formula and unit.

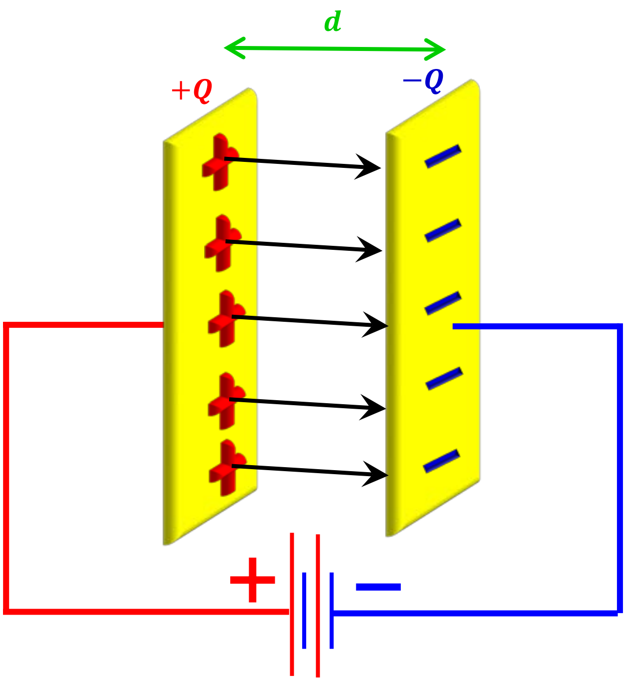
Ans: We know that the function of the resistance, which is widely used in the electrical circuit, is to waste energy! But a capacitor is a structure that stores energy and this stored energy can be used in the circuit in times of need.

Capacitor: A capacitor is a structure that stores energy in the form of an electric field.

A capacitor is a composite structure containing a dielectric material between two plates at a certain distance from each other.

As shown in the figure, when the capacitor is connected to a battery, the electron from the negative end of the battery is deposited on the negative plate of the capacitor, which exerts an unmet electric force on the electrons of the opposite metal plate, so the electrons from this plate returns to the battery and the plate becomes positively charged. If we take the accumulated electric charge on Q and voltage of the battery is V then,

$$Q \propto V$$



That is, as the value of the electric charge deposited on two plates increases, so does the value of its electric potential i.e., voltage.

Removing the proportionality sign,

$$Q = kV$$

Here the proportionality is represented by the constant k, which is known as the capacitance C of the capacitor.

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

The above equation shows that for any capacitor, the ratio of the electric charge deposited on its plate and the voltage generated between its two plates is always constant.

Thus, the value of the capacitance does not depend on the electric load on its plate or the voltage given to it.

(Just as water is added to a 1-liter bottle of size, the water level increases, but the size of the bottle, which is 1 liter, does not deteriorate.)

Que. 08. Explain parallel plate capacitor and derive an equation for capacitance.

Ans: According to the figure shown two plates having an area $\boldsymbol{A}$ and distance between two plate is $\boldsymbol{d}$. One plate of the capacitor has a positive electric charge and the other plate has a negative electric charge of the same value. We know that an electric field is formed around the electric charges which can be represented by the force lines.

Suppose that electric charges deposited on the positive and negative plates are $+Q$ and $-\boldsymbol{Q}$.

Now the electric charge density on the positive electrically charged plate holding the area A,

$$\sigma = \frac{Q}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Electric charge density on a negatively charged plate,

$$\sigma = -\frac{Q}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If the distance between two plates is very small with respect to the area $(A \gg d)$ then, the electric field produced by the plate,

$$E = \frac{\sigma}{2\epsilon_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Now in Area – 1, since the electric fields formed by the positive and negative plates are of opposite direction and of equal value,

$$E_1 = \frac{\sigma}{2\epsilon_0} + \left(-\frac{\sigma}{2\epsilon_0}\right) = 0$$

Similarly in Area – 3 also,

$$E_3 = \frac{\sigma}{2\epsilon_0} + \left(-\frac{\sigma}{2\epsilon_0}\right) = 0$$

Since the directions of the electric field formed by both the plates in Area – 2 are the same,

$$E_2 = E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0}$$

$$\boldsymbol{E_2} = E = \frac{\sigma}{\epsilon_0} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

We know that if $\boldsymbol{E}$ is the electric field formed by an electrically charged plate then at a distance the potential generated between them,

$$V = E \cdot d$$

$$V = \frac{\sigma}{\epsilon_0} \times d \dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Now putting the value of the

$$\sigma = \frac{Q}{A}$$

electric charge density in equation (5) above,

$$V = \frac{\frac{Q}{A}}{\epsilon_0} \times d$$

$$V = \frac{Qd}{\epsilon_{0A}} \dots\dots\dots\dots\dots\dots\dots\dots (6)$$

Here is the equation of the capacitance,

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

$$\therefore C = \frac{Q}{\frac{Qd}{\epsilon_0 A}}$$

$$\therefore \boldsymbol{C} = \frac{\boldsymbol{\epsilon_0 A}}{\boldsymbol{d}}$$

The above equation represents the value of capacitance of the capacitor.

The value of capacitance is determined by the main three components.

1. Plate area $(\boldsymbol{A})$ – As the area increases, so does the value of capacitance.
2. The distance between two plates $(\boldsymbol{d})$ – as the plate distance is smaller, the value of capacitance is larger.

3. Permeability (ϵ_0) – As the value of permeability increases, so does the value of capacitance.

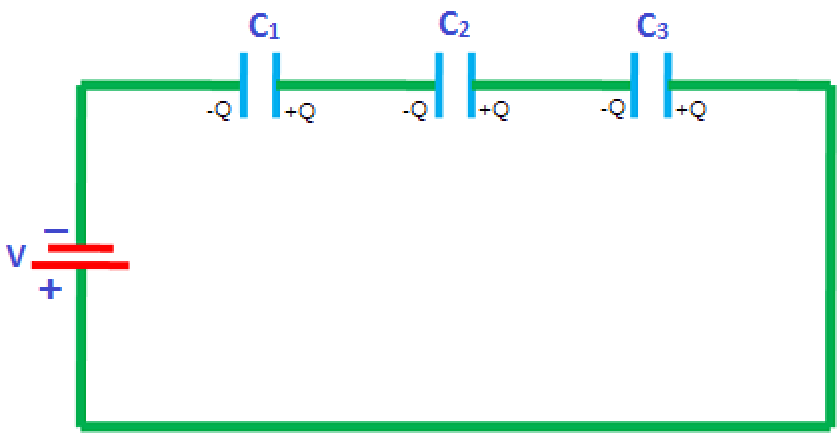
It is important to know here that the value of capacitance does not depend on the thickness of the plate or the type of material of the plate.

Que. 09. Explain series connection of capacitors and derive an equation for equivalent capacitance by drawing suitable circuit diagram.

OR

Draw a circuit a diagram for a connection in which the charge on plate of each capacitor connected in a circuit will be same and derive an equation for equivalent capacitance.

Ans: As shown in the figure, three capacitors C_1, C_2 and C_3 are connected to a battery with an electric potential V.



SERIES CONNECTION OF CAPACITOR

Series Connection: " If the given capacitor is connected in such a way that the electrical charge deposited on the plate of each of the capacitors is the same, then such connection is known as **series connection**."

$$\therefore Q = Q_1 = Q_2 = Q_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

As shown in the figure, the electrical charge deposited on the plate of all capacitors in the series connection remains same. Since the capacitance of each capacitor is different, their electric potential (Voltage) will be different.

According to the formula of capacitance,

$$V_1 = \frac{Q}{C_1}$$

$$V_2 = \frac{Q}{C_2}$$

$$V_3 = \frac{Q}{C_3}$$

If the total voltage supplied by the battery is V.

$$V = V_1 + V_2 + V_3 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Putting the values of V_1, V_2 and V_3 in the above equation,

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Equivalent capacitances for series connection

$$V = \frac{Q}{C_S} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Comparing equations (3) and (4),

$$\frac{Q}{C_S} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

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

The above equation is a formula showing the value of the equivalent capacitance of the three capacitors connected in the series. If there are n capacitors are connected in series, then equivalent capacitance,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots\cdots\cdots + \frac{1}{C_n}$$

Thus, the above equation shows that the value of equivalent capacitance in a series connection is even smaller than the smallest value of the capacitors in that connection.

Applications of Series connection of capacitors:

1. Capacitive Voltage Divider
2. Limiting Higher Working Voltage
3. Replacement of Battery with Serially connected Super Capacitors.

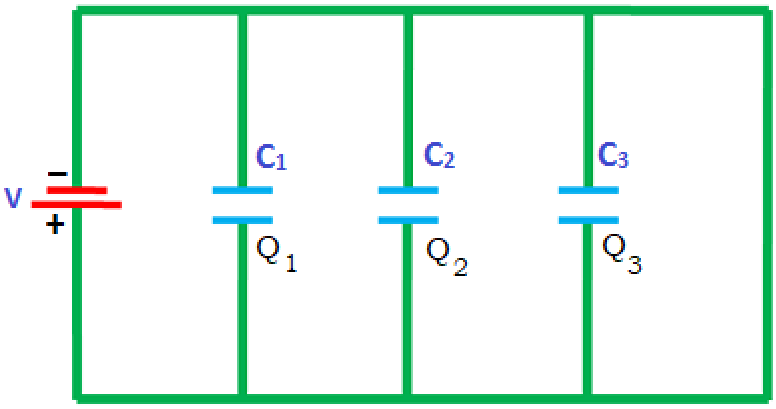
Que. 10. Explain parallel connection of capacitors and derive an equation for equivalent capacitance by drawing suitable circuit diagram.

OR

Draw a circuit a diagram for a connection in which the potential (Voltage) on across each capacitor connected in a circuit will be same and derive an equation for equivalent capacitance.

Ans: As shown in the figure, three capacitors C_1, C_2 and C_3 are connected to a battery with an electric potential equal to V.

Parallel Connection:
"A connection in which capacitors are connected in such a way that the difference in electric potential (voltage) across each capacitor remains same. Such a connection is known as parallel connection."



PARALLEL CONNECTION OF CAPACITORS

$$\therefore V = V_1 = V_2 = V_3$$

As shown in the figure, the electric charge deposited on the plates of three capacitors C_1, C_2 and C_3 is Q_1, Q_2 and Q_3 respectively.

$$Q_P = Q_1 + Q_2 + Q_3 \dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

For each capacitor, the value of charges will be,

$$Q_1 = C_1 V$$
$$Q_2 = C_2 V$$
$$Q_3 = C_3 V$$

If there is an equivalent capacitance C_P for parallel connection then,

$$Q = C_P V \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

And putting the values of Q_1, Q_2 and Q_3 into equation (1),

$$C_P V = C_1 V + C_2 V + C_3 V$$

$$C_P = C_1 + C_2 + C_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The above equation is a formula showing the equivalent capacitances for three capacitors connected in parallel. If n capacitors are connected in parallel then equivalent capacitance becomes,

$$C_P = C_1 + C_2 + C_3 + \cdots\cdots\cdots\cdots + C_n$$

Thus, the value of equilibrium capacitances in a parallel connection is larger than the value of a capacitor with the largest value of all capacitors in a parallel connection.

Applications of Parallel connection of capacitors:

1. D.C. Power supply
2. Capacitor Banks
3. Pulsed Loads
4. Super Capacitors

Que. 11. List the differences between series and parallel connection of capacitors.

Ans:

	Series Connection	Parallel Connection
1	If a given capacitors are connected in such a way that the electric charge deposited on the plate of each capacitor is of same value, then such a connection is known as series connection.	If a given capacitors are connected in such a way that the difference in electric potential across each capacitor is same then, such a connection is known as parallel connection.
2	The above equation shows that the value of equivalent capacitance in a series connection is even smaller than the smallest value of the capacitors in that connection.	The value of equilibrium capacitances in a parallel connection is larger than the value of a capacitor with the largest value of all capacitors in a parallel connection.

3	$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots + \frac{1}{C_n}$	$C_P = C_1 + C_2 + C_3 + \cdots\cdots\cdots + C_n$
4	Adding a capacitor in series to capacitors in the circuit reduces the value of the equivalent capacitance of the entire circuit.	Adding a capacitor in parallel to capacitors in the circuit increases the value of the equivalent capacitance of the entire circuit.
5	a) Capacitive Voltage Divider b) Limiting Higher Working Voltage c) Replacement of Battery with Serially connected Super Capacitors	a) D.C. Power supply b) Capacitor Banks c) Pulsed Loads d) Super Capacitors

Que. 12. Explain the effect of di-electric medium on the capacitance of parallel plate capacitor:

Ans:

According to The Coulomb's Law, the force between two charges $\boldsymbol{q_1}$ and $\boldsymbol{q_2}$ kept at a distance r placed in vaccum or in air is given by,

$$F_0 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 \boldsymbol{q_2}}{r^2} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If these electric charges $\boldsymbol{q_1}$and $\boldsymbol{q_2}$ are kept in a medium with permittivity $\boldsymbol{\varepsilon}$ then, the electric force exerted between them,

$$F_m = \frac{1}{4\pi\varepsilon}\frac{q_1 \boldsymbol{q_2}}{r^2} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Taking the ratio of equations (1) and (2),

$$\therefore \frac{F_0}{F_m} = \frac{\frac{1}{4\pi\varepsilon_0}\frac{q_{1q_2}}{r^2}}{\frac{1}{4\pi\varepsilon}\frac{q_{1q_2}}{r^2}}$$

$$\therefore \frac{F_0}{F_m} = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = K \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, ε_r is called relative permittivity or di-electric permeability of the medium (K)

The value of $\boldsymbol{K}$ is greater than 1.

The ratio of its capacitance when a di-electric medium is placed between two plates of the capacitor and when there is only vacuum/air between the two plates,

$$\varepsilon_r = \frac{\text{capacitance with dielectric medium is placed bet}^n \text{ two plates of the capacitor}}{\text{capacitance when vacuum/air is present bet}^n \text{ two plates of the capacitor}}$$

$$\varepsilon_r = K = \frac{C_m}{C_0} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\therefore C_m = K\,C_0 \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Thus, when di-electric material is placed between two plates of capacitor, the value of the capacitance increases $\boldsymbol{K}$ times. In other words, the capacity of such a capacitor to store electrical charge increases $\boldsymbol{K}$ times.

Now the capacitance of the capacitor having only **vacuum/air** between the two plates,

$$C_0 = \frac{\boldsymbol{\varepsilon_0}\, A}{d}$$

Putting this value of capacitance in equation (5),

$$\therefore C_m = K\,\frac{\boldsymbol{\varepsilon_0}\, A}{d} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

From equation (3),

$$\varepsilon = \varepsilon_r \boldsymbol{\varepsilon_0} = K\varepsilon_0$$

$$\therefore C_m = \frac{\varepsilon\, A}{d} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Equation (7) above is ε the law of capacitance found when a medium with the relative permeability is placed between two plates of capacitor.

PRACTICE NUMERICAL

1. **How many electrons make one coulomb ($\boldsymbol{1\ C}$) charge?**

   Solution:

   Here given electric charge, $\boldsymbol{Q = 1\ C}$

$$\boldsymbol{n} = ??$$

$$\boldsymbol{e = 1.6 \times 10^{-19}\ C}$$

Suppose that the amount of Q coulomb charge is formed by n electrons.

$$\therefore Q = ne$$

$$\therefore n = \frac{Q}{e} = \frac{1}{1.6 \times 10^{-19}} \frac{C}{C}$$

$$\therefore n = 6.25 \times 10^{18} \ electrons$$

Thus, one coulomb charge is formed with 6.25×10^{18} as many electrons.

2. Find the two electric charges $+\,2\mu C$ and $+\,4\ \mu C$ force arising between the two when placed $10\ m$ away. What kind of force will this force be?

Solution:

$$q_1 = +\,2\mu C = 2 \times 10^{-6}\ C$$

$$q_2 = +\,4\mu C = 4 \times 10^{-6}\ C$$

$$r = 10\ m$$

$$F = ?$$

According to the law of the family,

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

$$\therefore F = 8.99 \times 10^9 \times \frac{2 \times 10^{-6}\ \times 4 \times 10^{-6}}{(10)^2}$$

$$\therefore F = 71.92 \times 10^9 \times 10^{-12} \times 10^{-2}\ N$$

$$\therefore F = 71.92 \times 10^{-5}\ \ N$$

3. **The coins with two equal electric charges are lying on a table 1 m away. How much electric charge should there be on these two coins so that the force exerted between them is $2.0\ N$ and attracted.**

Solution: Since both coins have the same electric charge here,

$$q_1 = q_2 = q$$

$$F = 2.0\ N$$

$$r = 1\ m$$

According to the Coulomb's law,

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

$$\therefore F = \frac{1}{4\pi\epsilon_0}\frac{q \times q}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2}$$

$$\therefore q^2 = 4\pi\epsilon_0 r^2 \times F$$

$$\therefore q^2 = \frac{1}{8.99 \times 10^9}(1)^2 \times 2.0$$

$$\therefore q^2 = 0.2224 \times 10^{-9}$$

$$\therefore q^2 = 0.02224 \times 10^{-8}$$

$$\therefore q = \sqrt{0.02224 \times 10^{-8}}$$

$$\therefore q = \pm\, 0.472 \times 10^{-4}\ C$$

Since there seems to be an attractive force between the two coins here, one coin has money and the other coin has a debt.

4. A capacitor is made up of two circular plates with a radius of 5 cm. The distance between these plates is 1 mm. If this capacitor is connected to a 9 V battery, find the capacitance of this capacitor and the electric charge on each plate.

Solution:

$$r = 5\ cm = 5 \times 10^{-2}\ m$$

$$d = 1\ mm = 1 \times 10^{-3}\ m$$

$$V = 9\ volt$$

$$Q = ?$$

$$C = ?$$

Capacitance of the Capacitor,

$$C = \varepsilon_0 \frac{A}{d} = \varepsilon_0 \frac{\pi r^2}{d}$$

$$\therefore C = 8.85 \times 10^{-12} \times \frac{3.14 \times (5 \times 10^{-2})^2}{1 \times 10^{-3}}$$

$$\therefore C = 8.85 \times 10^{-12} \times \frac{3.14 \times 25 \times 10^{-4}}{10^{-3}}$$

$$\therefore C = 8.85 \times 10^{-12} \times \frac{3.14 \times 25 \times 10^{-4}}{10^{-3}}$$

$$\therefore C = 694.725 \times 10^{-12} \times 10^{-4} \times 10^{3}$$

$$\therefore C = 694.725 \times 10^{-13}\ F$$

$$\therefore C = 69.47 \times 10^{-12}\ F$$

$$\therefore C = 69.47\ \ pF$$

Now to find the electric charge,

$$Q = C \times V$$

$$\therefore Q = 69.47 \times 10^{-12} \times 9$$

$$\therefore Q = 625.23 \times 10^{-12}\ C$$

$$\therefore Q = 625.23\ \ pC$$

5. Calculate the equivalent capacitance of two capacitors $C_1 = 10\ \mu\mathrm{F}$ and $\mathrm{C_2} = 5\ \mu\mathrm{F}$ are connected in series and parallel.

Solution:

$$\mathrm{C_1} = 10\ \mu\mathrm{F}$$

$$\mathrm{C_2} = 5\ \mu\mathrm{F}$$

For a series connection,

$$\frac{1}{\mathrm{C_s}} = \frac{1}{\mathrm{C_1}} + \frac{1}{\mathrm{C_2}}$$

$$\therefore \frac{1}{\mathrm{C_s}} = \frac{1}{10} + \frac{1}{5}$$

$$\therefore \frac{1}{C_s} = \frac{1+2}{10} = \frac{3}{10}$$

$$\therefore C_s = \frac{10}{3} = 3.33\ \mu F$$

For a parallel connection,

$$C_P = C_1 + C_2$$

$$\therefore C_P = 10 + 5$$

$$\therefore C_P = 15\ \mu F$$

6. **The value of the two capacitors is given $C_1 = 16\,\eta F$ and $C_2 = 8\,\eta F$. If these two capacitors are connected in a series, find the value of the equivalent capacitances found. In addition, if battery of $12\ volt$ is connected with circuit, then find the electric charge accumulated on the plate of each capacitor and find the voltage across each capacitor.**

Solution:

$$C_1 = 16\,\eta F$$

$$C_2 = 8\,\eta F$$

$$V = 12\,volt$$

$$Q_1, Q_2 = ?$$

$$V_1, V_2 = ?$$

For a series connection,

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\therefore \frac{1}{C_s} = \frac{1}{16} + \frac{1}{8}$$

$$\therefore \frac{1}{C_s} = \frac{1+2}{16} = \frac{3}{16}$$

$$\therefore C_s = \frac{16}{3} = 5.33\ \eta F$$

We know that the electrical charge deposited on the plate of each capacitor in the series connection remains the same.

$$Q_1 = Q_2 = Q$$

Now to find the electric charge,

$$Q = C \times V$$

$$\therefore Q = 5.33 \times 12$$

$$\therefore Q = 63.96\, \eta C \sim 64\, \eta C$$

$$\therefore Q = Q_1 = Q_2 = 64\, \eta C$$

Now to find the voltage between the b plates of each capacitor,

For the first capacitor,

$$V_1 = \frac{Q_1}{C_1} = \frac{Q}{C_1} = \frac{64}{16}$$

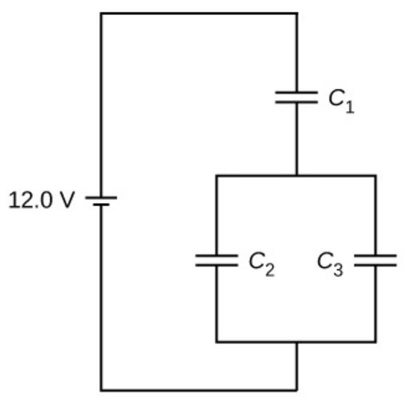
$$\therefore V_1 = 4\ volt$$

For the second capacitor,

$$V_2 = \frac{Q_2}{C_2} = \frac{Q}{C_2} = \frac{64}{8}$$

$$\therefore \boldsymbol{V_2 = 8\ volt}$$

7. The three capacitors given here are connected to a battery of 12 volt as shown in the figure. Given $C_1 = 3\ \mu F$, $C_2 = 6\ \mu F$ and $C_3 = 9\ \mu F$. Find the equivalent capacitance for this connection, and find the voltage across each capacitor and the electric charge on each capacitor.



Solution:

$$C_1 = 3\ \mu F$$

$$C_2 = 6\ \mu F$$

$$C_3 = 9\ \mu F$$

Now C_2 and C_3 are in series connection so,

$$C_{23} = \frac{C_2 \times C_3}{C_2 + C_3}$$

$$C_{23} = \frac{6 \times 9}{6 + 9} = \frac{54}{15}$$

$$\therefore C_{23} = \frac{18}{5} = 3.6\ \ \mu F$$

OR

You can use this convectional formula to calculate C_{23}

$$\frac{1}{C_{23}} = \frac{1}{C_2} + \frac{1}{C_3}$$

$$\therefore \frac{1}{C_{23}} = \frac{1}{6} + \frac{1}{9}$$

$$\therefore \frac{1}{C_{23}} = \frac{3 + 2}{18} = \frac{5}{18}$$

$$\therefore C_{23} = \frac{18}{5} = 3.6\ \ \mu F$$

C_{23} being in parallel connection with C_1,

$$C_P = C_1 + C_{23}$$

$$\therefore C_P = 3 + 3.6$$

$$\therefore C_P = 6.3\ \ \mu F$$

Equivalent capacitance of a given circuit $C_P = 6.3\ \ \mu F$

We know that voltage across each capacitor between the two plates in the connection for a parallel connection remains the same and its value is the same as the voltage supplied by the battery.

Here C_{23} and C_1 is connected in parallel.

Therefore,

$$V_1 = V_{23} = V = 12\ volt$$

Now to find the electric charge,

$$Q_1 = C_1 \times V_1$$

$$\therefore Q_1 = 3 \times 12$$

$$\therefore Q_1 = 36\ \mu C$$

We know that the electric charge deposited on the plate of each capacitor in a series connection remains the same. here C_2 and C_3 are in series, the electric charge on their plate will remain the same.

$$Q_2 = Q_3$$

$$Q_2 = C_{23} \times V_{23}$$

$$\therefore Q_2 = 3.6 \times 12$$

$$\therefore Q_2 = 43.2\ \ \mu C = Q_3$$

$$\therefore Q_3 = 43.2\ \ \mu C$$

Now to find the voltage between the b plates of each capacitor,

For the capacitor C_2,

$$V_2 = \frac{Q_2}{C_2} = \frac{43.2}{6}$$

$$\therefore V_2 = 7.2\ volt$$

For the capacitor C_3,

$$V_3 = \frac{Q_3}{C_3} = \frac{43.2}{9}$$

$$\therefore V_3 = 4.8\ volt$$

 # Check point: We will check whether total voltage across C_2 and C_3 is equal to the voltage supplied by the battery.

$$V_2 + V_3 = 7.2 + 4.8 = 12\ volt = V$$
$$= Voltage\ supplied\ by\ the\ battery$$

Thus, all the results,

Equilibrium capacitance, $C_P = 6.3\ \mu F$

The electric charge on each capacitor,

$$Q_1 = 36\ \mu C,\ \ Q_2 = Q_3 = 43.2\ \mu C$$

Voltage across on each capacitor,

$$V_1 = 12\ \text{volt},\ V_2 = 7.2\ \text{volt},\ V_3 = 4.8\ \text{volt}$$

8. Spark plug is used for the combustion of petrol in a bike or car. In which there is a gap of 0.6 mm between two electrodes. Find the value of the electric field required to generate the $3 \times 10^6\ V/m$ spark. Then find the voltage supplied to this spark plug. If this gap is increased, what will be the value of the voltage required for the spark? Find the required voltage if this gap is reduced to 1 mm.

Solution:

$$d = 0.6\ mm = 0.6 \times 10^{-3}\ \ m$$

$$V = 3 \times 10^6\ V/m$$

$$E = ?$$

If there $\boldsymbol{d}$ is a distance between two plates and the amount of voltage mounted between them is $\boldsymbol{V}$ and the electric field arising between the two plates is $\boldsymbol{E}$,

$$\boldsymbol{V = E \cdot d}$$

$$\therefore V = 3 \times 10^6\ \frac{V}{m}\ \times 0.6 \times 10^{-3}\ \ m$$

$$\therefore V = 1.8 \times 10^3\ \ volt$$

$$\therefore V = 1800\ \ volt$$

If the electric field is constant, the voltage between the two plates is proportional to the distance between the two plates.

$$V \propto d$$

So as the distance between two plates increases, so does the value of the voltage required for two plates will also increase.

The distance between the two plates here, $d = 1\,mm = 1 \times 10^{-3}\ m$

$$\therefore V = E \cdot d$$

$$\therefore V = 3 \times 10^{6}\ \frac{V}{m}\ \times 1 \times 10^{-3}\ m$$

$$\therefore V = 3 \times 10^{3}\ V$$

$$\therefore V = 3000\ V$$

Hence the value of the voltage required when there is a distance between two plates $1\,mm$ is $V = 3000\,volt$.

9. Two metal plates are connected to a 45 volt battery. Find the distance between these two plates if there is an electric field generated by the battery between the two plates is $1500\ N/C$.

Solution:

$$V = 45\,volt$$

$$E = 1500\frac{N}{C}$$

$$d = ?$$

$$V = E \cdot d$$

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

$$\therefore d = \frac{45\ Volt}{1500\frac{N}{C}}$$

$$\therefore d = 0.03\ m$$

$$\therefore d = 3\ cm$$

The other unit of the electric field is $[E] = \frac{N}{C} = \frac{V}{m}$

10. The work required to bring $2.0\ C$ of electric charge from point X to point Y is $10.0\ J$. Then find the difference in the electric potential between these two points.

Solution:

$$q = 2.0\ \ C$$

$$W = 10.0\ \ J$$

$$V = ?$$

The work that has to be done to bring the electric charge q from one X point to another point Y,

$$W = \frac{V_{XY}}{q}$$

$$\therefore V_{XY} = V = W \times q$$

$$\therefore V = 10.0 \times 2.0$$

$$\therefore V = 20\ volt$$

11. Two plates kept at $0.40\ cm$ each other are projected to electric field of $6400\ N/C$. Find the work required to transfer electric charge of $0.25\ \ \mu C$ from one plate to another plate.

Solution:

$$d = 0.40\ cm = 0.40\ \times 10^{-2}\ \ m$$

$$E = 6400\ \ \frac{N}{C}$$

$$q = 0.25\ \ \mu C = 0.25 \times 10^{-6}\ \ C$$

$$W = ?$$

voltage arising between two plates,

$$V = E \cdot d$$

$$\therefore V = 6400\ \ \frac{N}{C}\ \times 0.40 \times 10^{-2}\ \ m$$

$$\therefore V = 2560 \times 10^{-2}\ \ volt$$

$$\therefore V = 25.60 \;\; volt$$

We will find work using this value.

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

$$\therefore W = \frac{25.60 \;\; volt}{0.25 \times 10^{-6} \;\; C}$$

$$\therefore W = 102.4 \times 10^{6} \;\; J = 1.02 \times 10^{8} \;\; J$$