CONTINUATION OF ELECTROSTATICS NOTES.

The Van de Graaf Generator

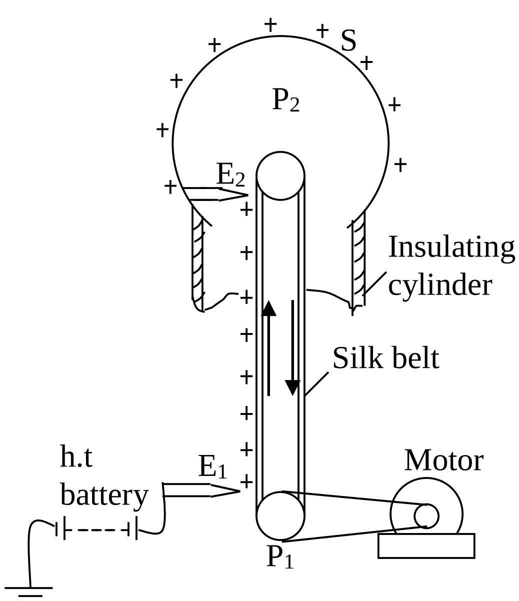
(a) *Industrial Type*

This uses the discharging action and the collection action of points.

Features: It consists of a hollow metal sphere S supported on an insulating cylinder T several metres high. A silk belt B runs over pulleys P_1 and P_2, the lower being driven by a motor. Near the top and bottom the belt passes close to the electrodes E_1 and E_2, which are sharply pointed combs.

Action:

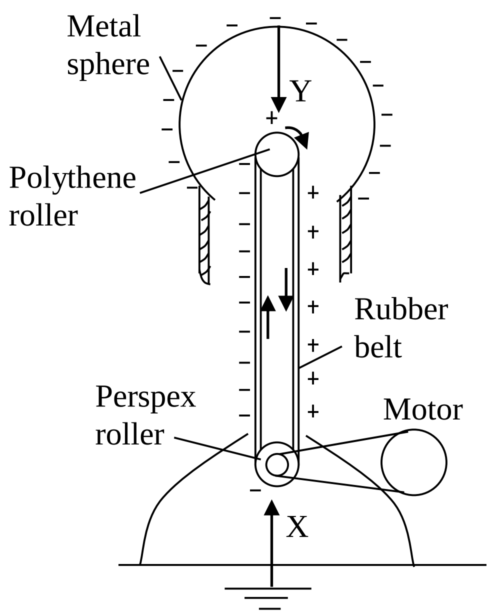
E_1 is given a potential of about 10,000 volts, positive with respect to the earth, by a battery. The high electric field at the points of E_1 ionises the air there, positive charges being repelled to the belt.



The belt carries them up into the sphere. The positive charge induces a negative charge on the points of E_2 and a positive charge on the sphere. The high electric field at the points of E_2 ionises the air there, and negative charge is repelled to the belt thereby discharging it before it passes over the pulley P_2. Thus, the sphere gradually charges up positively to millions of volts with respect to the earth.

The electrical energy generated by this machine comes from the work done by the motor in driving a positively charged belt into a positively charged sphere.

(b) School Version



This type does not use any battery for the initial charge. Initially a positive charge is produced on the lower Perspex roller by friction between it and the rubber belt. This charge induces a negative charge on the tips of a metallic comb X whose blunt end is earthed. Electrons are drawn from the earth and due to a high electric field at the tips, the air there is ionized thereby repelling the negative charge to the rubber, which carries it into the sphere. When the negative charge reaches near comb Y electrostatic induction occurs in Y with the negative charge being repelled to the outside of the sphere. The positive charge on the tips of Y creates a high electric field there causing ionization of the air there.

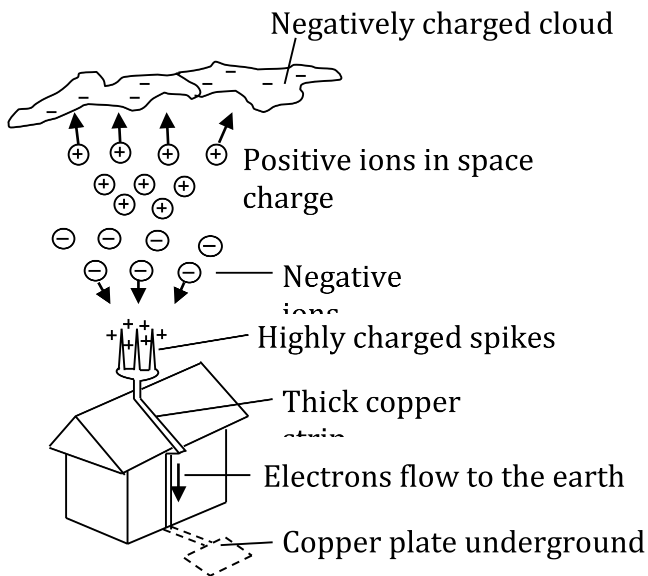
Positive charge is repelled onto the belt, neutralizing all the negative charge on it and giving some positive charge to the belt. The cycle continues until a very high potential is developed on the sphere.

Factors Determining the Maximum Potential Developed

(i) Height of the metal sphere above the ground – a greater height gives a greater maximum potential.
(ii) Size of the sphere – the bigger the sphere the greater the maximum potential.
(iii) Condition of the atmosphere – whether dump or dry. Dry atmosphere results in a greater maximum potential.

The Lightning Conductor

A lightning conductor is an application of collection of the action of points. It consists of a thick copper strip whose lower end is connected to a copper plate buried in the ground while its upper end is in form of pointed spikes.



Action:
When a cloud, charged say negatively, passes above the spikes, electrostatic induction occurs in the copper strip the electrons being repelled to the buried plate and hence to the ground while the spikes remain positively charged.
The charge concentrates at the tips of the spikes causing a high electric field there which results in ionisation of the air around. The positive ions so formed are repelled to the cloud to partially neutralize it while the negative ions are attracted to the spikes thereby neutralising them also.
The net result is that negative charge has been safely passed from the cloud to the ground through the copper strip.

COULOMB'S LAW OF ELECTROSTATICS (The law of forces on charges)

This states that the force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of their distance apart.
Let F be the force, Q_1 and Q_2 the charges and r the separation.
Then

$$F \propto \frac{Q_1Q_2}{r^2} \text{ or } F = k\frac{Q_1Q_2}{r^2}$$

where k is a constant written as $\frac{1}{4\pi\varepsilon}$.

[read as one over four pi epsilon]

where ε is a constant known as ***permittivity*** of the medium in which the charges are located. It is a measure of the medium's ability to reduce the force between charges.
Thus

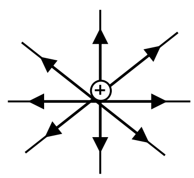
$$\mathbf{F = \frac{Q_1Q_2}{4\pi\varepsilon r^2}}$$

For vacuum ε_o *[read as epsilon nought]* = 8.85×10^{-12} Fm^{-1}

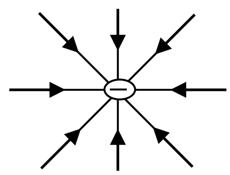
ELECTRIC FIELDS

An electric field is a region where an electric force is experienced. It can be represented by imaginary lines of force called Electric field (flux) lines. An electric field line of force through a point indicates the path and direction a point positive charge would take if placed there.

Examples of Electric field (flux) patterns.

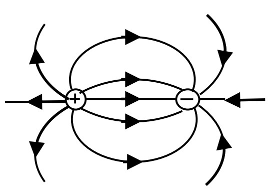


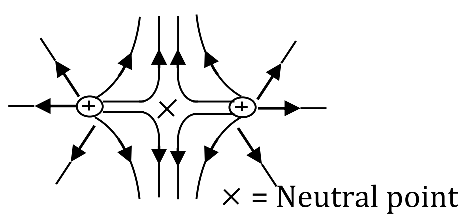
(i)Point positive charge



(ii)Point negative charge

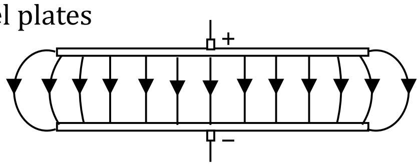
These lines emanate from a positive charge and end onto a negative charge. They **NEVER** cross each other. Therefore, electric field lines are always in a state of tension.



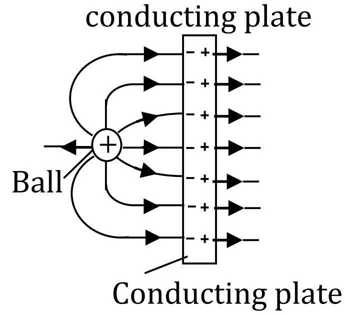


Note: A neutral point is a point where no net electric force can be experienced due to presence of two equal and opposite electric field intensities.

Parallel plates



Charged Ball near a conducting plate



Properties of electric field lines

1. They originate from positive and end on negative.
2. they are in a state of tension which causes them to shorten
   they repel one another side ways
3. they travel in straight lines and never cross each other
   the number of filed lines originating or terminating on a charge is proportional to the magnitude of the charge

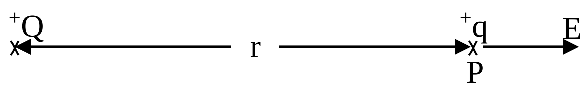
Electric Intensity

The electric intensity (or field intensity) at a point in an electric field is the force experienced by a positive charge of one coulomb placed at that point.
It is a vector quantity and is unit is NC^{-1} (newton per coulomb)

Electric (Field) Intensity due to a Point Charge

The magnitude of the electric intensity, E, due to an isolated positive point charge, ^+Q, at a point P, a distance r away, in a medium of permittivity ε is required.

Imagine a small point charge ^+q placed at point P.



By Coulomb's law, the force on ^+q is

$$F = \frac{Qq}{4\pi\varepsilon r^2}$$

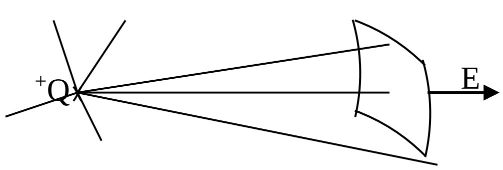
But E is the force per unit charge.

$$\text{i.e} \qquad E = \frac{F}{q} = \frac{Q}{4\pi\varepsilon r^2}$$

From this it is clear that the electric intensity at a point is inversely proportional to the square of the distance of the point from the charge

Flux from a Point Charge

This is the total number of electric lines of force emanating from the point charge. Electric intensity, E, at any point can be represented by a number of lines per unit area through a surface perpendicular to the lines of force at the point considered.



At a distance r from the charge the surface that will be pierced by all the lines due to Q is a sphere of radius r concentric with the point charge Q. So at a distance r from the charge the flux is

$\Phi = E \text{ x area} = E \text{ x } 4\pi r^2$

So $\Phi = \dfrac{Q}{4\pi\varepsilon r^2} \text{ x } 4\pi r^2 = \dfrac{Q}{\varepsilon} = \dfrac{\text{Charge inside sphere}}{\text{Permittivity}}$

Electric Intensity due to a Charged Sphere

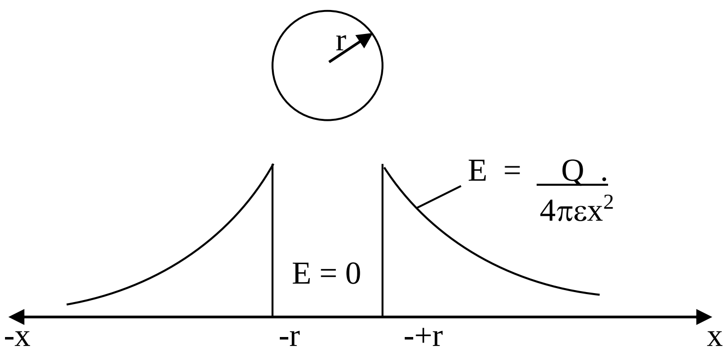
(i) Outside the Sphere

$\text{Flux} = \dfrac{Q}{\varepsilon}$

$\therefore \quad E \text{ x } 4\pi r^2 = \dfrac{Q}{\varepsilon}$

$\therefore E = \dfrac{Q}{4\pi\varepsilon r^2}$ (same as for a point charge)

(ii) Inside a charged hollow sphere the charge is zero. So the electric intensity, E, is also zero.



Electric Intensity and Surface Density, σ

For a sphere of radius r, having charge Q, $\sigma = Q/4\pi r^2$

$\therefore Q = 4\pi r^2\sigma$ ……………………………………….(1)

But flux $\Phi = E \text{ x area} = \dfrac{Q}{\varepsilon}$

$\therefore \quad E \text{ x } 4\pi r^2 = \dfrac{Q}{\varepsilon}$

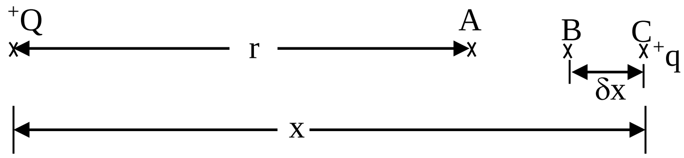
Substituting for Q from (1) $\mathbf{E} = \dfrac{\boldsymbol{\sigma}}{\boldsymbol{\varepsilon}}$ … … … … … … … . . . . (2)

Electric Potential

The electric potential at a point in a field is the work done in moving a positive charge of one coulomb from infinity to the point against electrostatic repulsion.

Potential Due to a Point Charge

Suppose the potential at a point A in a field of an isolated point charge ^+Q at O in a medium of permittivity ε is required. Then imagine a small point charge q placed at point C, distance x from O.



The force acting on q is F $= \frac{Qq}{4\pi\varepsilon x^2}$

Suppose q is now moved a small distance δx to B without affecting the field due to ^+Q. Over this small distance δx, the force F may be assumed constant. So the work done by the external agent over δx against the force of the field is

$\delta W = F(-\delta x)$

$\therefore \delta W = \frac{Qq(-\delta x)}{4\pi\varepsilon x^2}$

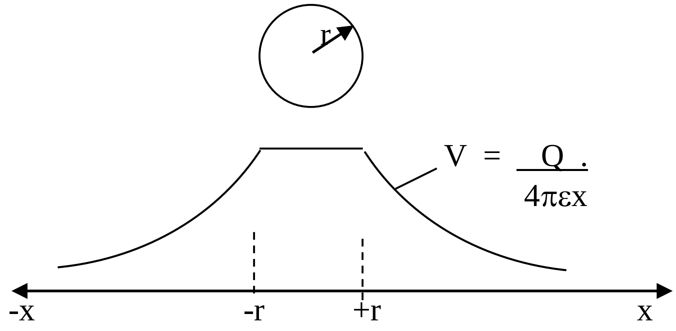
The total work done in bringing q from infinity to A is

$$W = \frac{-Qq}{4\pi\varepsilon}\int_{\infty}^{r}\frac{1}{x^2}dx = \frac{-Qq}{4\pi\varepsilon}\left[\frac{-1}{x}\right]_{\infty}^{r} = \frac{Qq}{4\pi\varepsilon r}$$

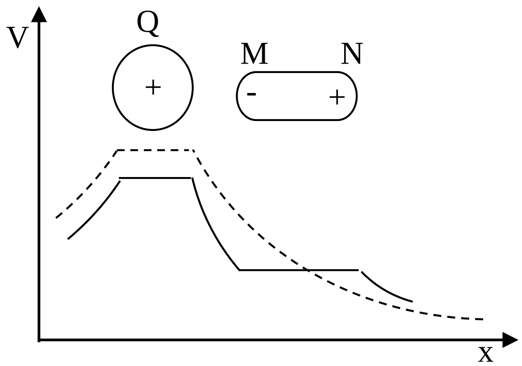
The potential V_A at point A is the work done per unit positive charge brought from infinity to A.

Hence $V_A = \frac{W}{q} = \boldsymbol{\frac{Q}{4\pi\varepsilon r}}$

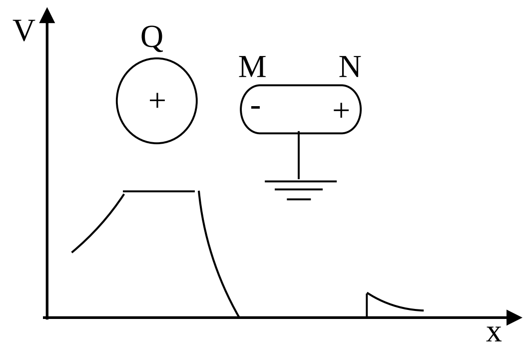
The graph below is a sketch of the potential distribution over and around a conducting sphere



When a conductor is brought near a positive charge the distribution is affected as shown below. The broken line shows the distribution before bringing up the conductor and the unbroken is for that after.



(i) Conductor not earthed



(ii) Conductor earthed

On the right is a graph for the potential distribution when the conductor is earthed.

When the neutral conductor is brought near the charge, electrostatic induction occurs in the conductor as shown. The negative charge at M lowers the potential there and at all points up to Q. The induced positive charge at N raises the potential there and at points beyond. Since MN is a conductor, electrons flow from N to M until the potential is the same all over MN – horizontal portion.

When the conductor is earthed, the potential all over MN is zero although it bears charges at its ends as shown.

Worked out Examples:

Take the quantity $\frac{1}{4\pi\varepsilon}$ to be $9.0 \text{ x } 10^{9} \text{ mF}^{-1}$

1. Q_1 and Q_2 are point charges separated by a distance of 5.0cm, where $Q_1 = 4.0\ \mu C$ and $Q_2 = 3.0\ \mu C$.

Find: (i) the potential energy of Q_1

(ii) the location of a point P, along Q_1Q_2, where the electric intensity is zero

(iii) the electric potential at P

Solution:

(i) Potential energy of Q_1 = Q_1 x potential of Q_2 there

$$= \frac{Q_1 Q_2}{4\pi\varepsilon r} = \frac{4.0 \text{ x } 10^{-6} \text{x } 3.0 \text{ x } 10^{-6} \text{x } 9.0 \text{ x } 10^{9}}{5.0 \text{ x } 10^{-2}}$$

= <u>0.216 J</u>

(ii) Let P be x cm from Q_1

At P the intensities are equal in magnitude but opposite in direction

$$\therefore \frac{Q_1}{4\pi\varepsilon x^2} = \frac{Q_2}{4\pi\varepsilon(5-x)^2}$$

$$\therefore \frac{4}{x^2} = \frac{3}{(5-x)^2}$$

$\therefore \quad x^2 - 40x\ 100 = 0$

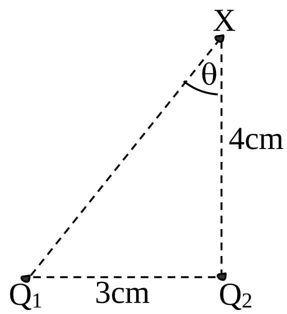
$\therefore \quad x = 37.3$ or 2.7

Since must be less than 5 cm, we take 2.7 cm. So P is 2.7 cm from Q_1.

(iii) $V_p = V_1 + V_2 = \dfrac{Q_1}{4\pi\varepsilon x} + \dfrac{Q_2}{4\pi\varepsilon(5-x)} = \left(\dfrac{4}{2.7} + \dfrac{3}{2.3}\right) x\ 10^{-6} x\ 9\ x\ 10^9$

$= \underline{2.51 \text{ x } 10^4 \text{ V}}$

2. In the figure Q_1 and Q_2 are point charges of 3.0 μC and 2.0 μC



Find: (i) the electric potential at point X

(ii) the electric intensity at point X

Solution:

(i) $V_X = V_1 + V_2$ (an algebraic sum)

$$= \frac{Q_1}{4\pi\varepsilon r_1} + \frac{Q_2}{4\pi\varepsilon r_2}$$

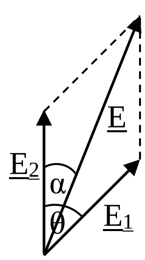
$$= \frac{1}{4\pi\varepsilon}\left(\frac{Q_1}{r_1} + \frac{Q_2}{r_2}\right)$$

$$= 9 \text{ x } 10^9 \left(\frac{3}{5} + \frac{2}{4}\right) \text{ x } \frac{10^{-6}}{10^{-2}} = \underline{9.9 \text{ x } 10^5} \text{ V}$$

(ii) For the intensity a vector diagram is needed since vectorial quantities are to be added. However care must be taken to get the directions of the vectors correct. ***If the intensity is positive, its vector is directed away from the charge producing it while if it is negative its vector is directed towards the charge producing it.*** See the vector diagram below for this question.

Let $\underline{E_1}$ be the intensity due to Q_1 at point X and $\underline{E_2}$ that due to Q_2.

$\underline{E}$ is the resultant electric intensity at point X



The magnitudes of the vectors are found as follows:

$$E_1 = \frac{Q_1}{4\pi\varepsilon r_1} = \frac{3 \text{ x } 10^{-6} \text{x } 9 \text{ x } 10^9}{5^2 \text{ x } 10^{-4}} = 1.08 \text{ x } 10^7 \text{ NC}^{-1}$$

$$E_2 = \frac{Q_1}{4\pi\varepsilon r_2} = \frac{2 \text{ x } 10^{-6} \text{x } 9 \text{ x } 10^9}{4^2 \text{ x } 10^{-4}} = 1.125 \text{ x } 10^7 \text{ NC}^{-1}$$

$E^2 = E_1^2 + E_2^2 + 2E_1E_2\cos\theta$, where $\cos\theta = 4/5$

$= (1.08^2 + 1.125^2 + 2 \text{ x } 1.08 \text{ x } 1.125 \text{ x } 4/5) \text{ x } 10^{14}$

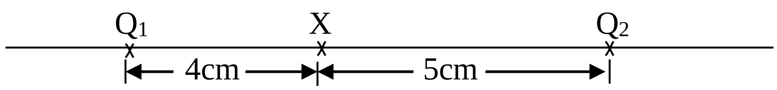
$= 4.38 \text{ x } 10^{14}$

$\therefore \quad E = \underline{2.09 \text{ x } 10^7 \text{ NC}^{-1}}$

Also $\quad \sin\alpha = \dfrac{E_1 \sin\theta}{E} = \dfrac{1.08 \text{ x } 3/5}{2.09} = \underline{0.310}$

$\therefore \alpha \;=\; 18^o$

3. The diagram below shows point chargesQ_1 a nd Q_2 lying on a straight line.
$Q_1 = -3.0\ \mu C$ and $Q_2 = 2.0\ \mu C$. Find



Find (i) the work done in bringing a charge of 2μC from infinity to point X.
(ii) a point P on the line where the electric intensity is zero.

Solution:
(i) Work done = charge moved from infinity x potential at X

$$= \frac{1}{4\pi\varepsilon}\left(\frac{Q_1}{r_1} + \frac{Q_2}{r_2}\right)$$

$$= 2 \text{ x } 10^{-6}\left(\frac{-3}{4} + \frac{2}{5}\right) \text{ x } \frac{10^{-6}}{10^{-4}} \text{ x } 9 \text{ x } 10^{9} \;=\; \underline{-0.63 \text{ J}}$$

(ii) Since Q_1 is negative the point where the two intensity vectors will be equal but opposite should be on the right hand side of both charges.
The magnitudes of the charges must be equal at P.
Let P be x cm to the right of Q_2.

Then $\quad \dfrac{Q_1}{4\pi\varepsilon(9 + x^2)} = \dfrac{Q_2}{4\pi\varepsilon x^2}$

$\therefore \dfrac{3}{(9 + x^2)} = \dfrac{2}{x^2}$

$\therefore \quad 3x^2 = 162 + 36x + 2x^2$

$\therefore \quad x = 40.0 \text{ or } -4.0$

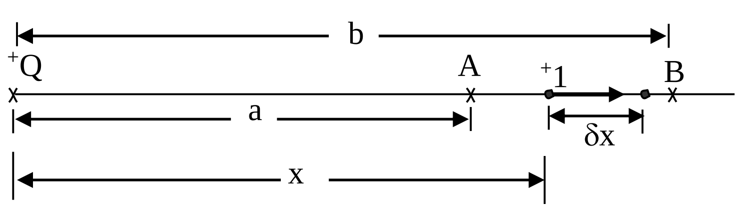
Since P must be on the right, it is 40.0 cm away from Q_2.

Potential Difference

The potential difference (p.d) between points A and B, denoted by V_{AB}, is the work done in moving a unit positive charge from B to A. Two points A and B are at a p.d of 1 volt if the work done in taking one coulomb of positive charge from B to A is 1 joule.

Potential Difference Formula

Consider two points A and B in the field of a single point positive charge Q, where A and B lie on a line of force at distances a and b respectively from the charge.



The force on a unit positive charge at a distance x from the charge Q in space is

$$f = \frac{Q \times 1}{4\pi\varepsilon x^2}$$

Over a short distance δx the work done in moving a unit positive charge in the direction BA is

$$\delta W = f(-\delta x) = \frac{Q(-\delta x)}{4\pi\varepsilon x^2}$$

Therefore over the whole distance AB, the work done is

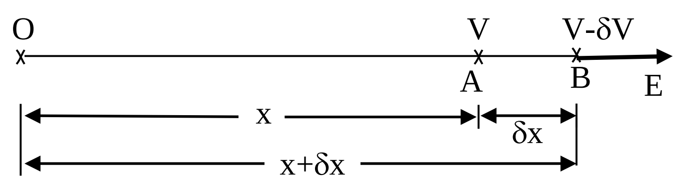
$$W = \int_B^A \delta W = \int_b^a \frac{-Qdx)}{4\pi\varepsilon x^2} = \boldsymbol{\frac{Q}{4\pi\varepsilon}\left(\frac{1}{a} - \frac{1}{b}\right)}$$

This is the p.d V_{AB} between A and B. i.e it is the potential at A minus the potential at B.
An electron-volt (eV) is the kinetic energy gained by an electron accelerated through a p.d of 1 volt. Since the work done in moving a charge Q through a p.d V is QV, it follows that 1 eV = electronic charge x 1

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

Relation between Intensity and Potential

Suppose there two points A and B on a line of, so close together that the electric intensity, E, between them may be regarded as constant.



If V is the potential at A, V-δV is that at B (since V decreases with distance) and the respective distance of A and B from O are x and x+δx, then

$$V_{AB} = V_A - V_B = V - (V - \delta V) = \delta V$$

The work done in taking a unit charge from B to A

$$= \text{force x distance} = E \times (-\delta x) = V_{AB} = \delta V$$

$$\therefore \quad E = -\frac{\delta V}{\delta x} = -\frac{dV}{dx}$$

The quantity $\frac{dV}{dx}$ is the potential gradient. Thus, E has units like Vm^{-1}

Worked Example:

A negatively charged oil drop of mass 2.0 x 10^{-14} kg is held stationary in the space of two horizontal parallel plates separated by a distance of 5.0 mm. If the p.d between the plates is 1530V, find the number of electrons on the drop.

[electronic charge, e = 1.6 x 10^{-19} C]

Solution:

The electric force on the drop = the weight of the drop

Let n = number of electrons on the drop

V = p.d between the plates

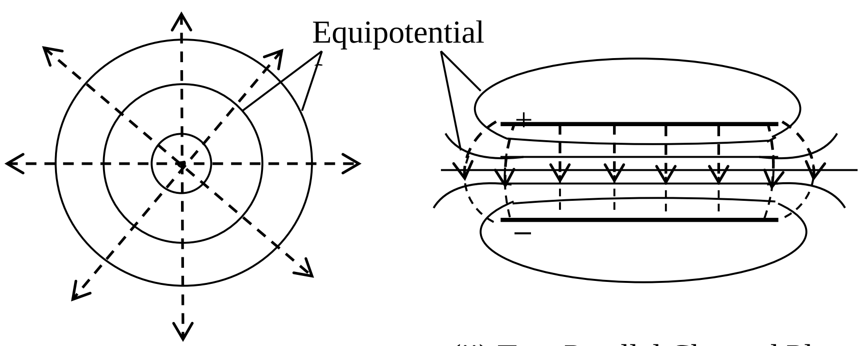
d = the distance between the plates

Then $ne\frac{V}{d} = mg$

$$\therefore \quad n = \frac{mgd}{Ve} = \frac{2.0 \times 10^{-14} \times 9.8 \times 5.0 \times 10^{-3}}{1530 \times 1.6 \times 10^{-19}} = 4$$

Equipotentials

An equipotential is any surface or volume over which the electric potential is constant.

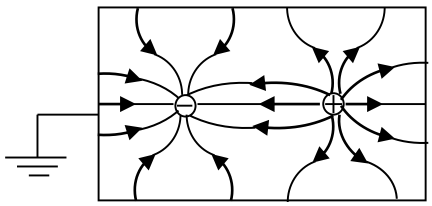


(i) Point Charge (ii) Two Parallel Charged Plates

Equipotentials meet the electric lines of force at right angles. The surface of a charged conductor is itself an equipotential. Therefore, the work done to move charge on the surface of a conductor is zero. This implies that the component of the electric force along the surface of the conductor is zero. Hence, electric field lines are perpendicular to the surface of the conductor – no tangential component.For the same reason electric field lines meet the equipotentials at right angles

Electrostatic Shielding:

This is applied in order to:
(i) protect devices from intense electric field in the region, or
(ii) prevent charge in one place from setting up an electric field beyond its immediate neighbourhood.
It is achieved by enclosing the device in a conductor and in the second case the outside of the shield is earthed.

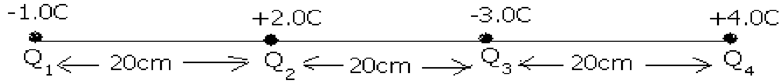


Exercise

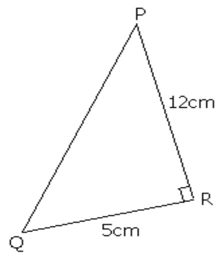
Two points charges A and B of $47.0\mu C$ and $24.0\mu C$ respectively are placed in vacuum at a distance of
30cm apart. When a third charge C of $-35.0\mu C$ is placed between A and B at a distance of 20cm
from A. find the net force on C An(-643.2N)
2. Two point charges of $5\mu C$ and $2\mu C$ are placed in liquid of relative permittivity 9 at distance 5cm apart.
Calculate the force between them. An(3.998N)
3. Two insulating metal spheres each of charge $5x10^{-8}\ C$ are separated by distance of 6cm. What is the
force of repulsion if;
(a) The spheres are in air Ans (0.00625N)
(b) The spheres are in air with the charge in each sphere doubled and their distance apart is
halved An(0.1N)
(c) The two sphere are placed in water whose dielectric constant is 81 An($\mathbf{7.\ 7x10^{-5}\ N}$)

Exercise on Electrostatics.

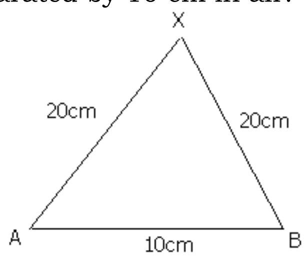
1. A conducting sphere of radius 9.0 cm is maintained at an electric potential of 10 kV. Calculate the charge on the sphere.
2. The figure below shows charges Q_1, Q_2, Q_3 and Q_4 of -1.0 C, +2.0 C, -3.0 C and +4.0 C arranged in a straight line in vacuum.



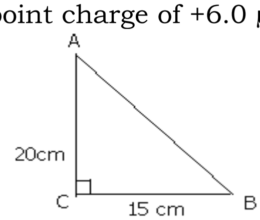
(i) Calculate the potential energy of Q_2.
(ii) What is the significance of the sign of the potential energy?
3. Two point charges of +3.8 μC and +5.2 μC are placed in air at points P and Q as shown in the diagram below. Determine the Electric field intensity at R.



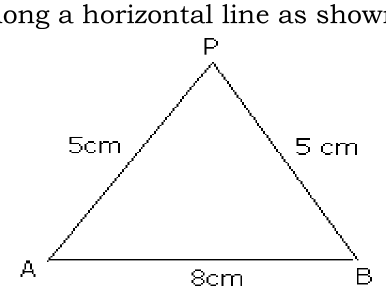
4. The electric field intensity at the surface of a sphere is 120 Vm^{-1} and points towards the centre of the earth. Assuming that the earth is a sphere of radius 6.4 x 10^6 m, find the magnitude and sign of the charge held by the earth's surface.
5. Two point charges of +4.0 μC and -4.0 μC are placed at points A and B respectively, separated by 10 cm in air.



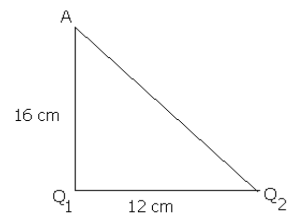
Find the electric field intensity at point X, a distance 20 cm from each of the charges.
6. Consider two points A and B at a distance of 15.0 cm and 20.0 cm respectively form a point charge of +6.0 μC placed at C as shown below.



(i) Find the electric potential difference between A and B.
(ii) Calculate the energy required to bring a charge of +1.0 μC from infinity to point A.
(iii) Calculate the work done in bringing a charge of 2.0 μC from A to a point half way along AB.
7. Alpha particles (charge = +2e), each having kinetic energy of 1.0 x 10^{-12} J are incident head-on a gold nucleus (charge = +79e) in a gold foil. Calculate the distance of closest approach for alpha particles to the gold nucleus.
8. Two point charges A and B of +0.1 μC and +0.050 μC are separated by a distance of 8.0 cm along a horizontal line as shown.

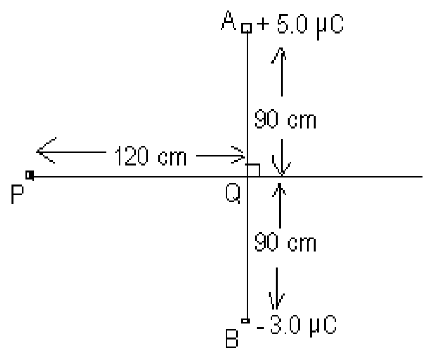


(i) Find the electric field intensity at P.
(ii) Sketch the electric field pattern due to the charge distribution in the diagram above.
(iii) Find the location of a point X on AB at which the electric intensity is zero.
9.



A is a point **16 cm** from a point charge Q_1. Another point charge Q_2 is located **12 cm** from Q_1 as shown in figure 2. If **Q_1 = 4 μC and Q_2 = 6 μC**, calculate the work done in transferring a charge of **2 μC** from point A to a point mid-way between A and Q_1.

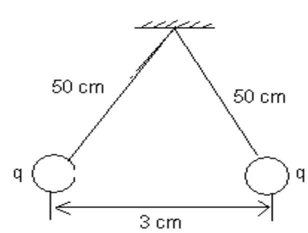
10. Two point charges **+5.0 μC** and **-3.0 μC** are placed at points A and B as shown in the figure below Calculate the *work done* in moving a test charge of **-2.0 μC** from P to Q..



11. Two point charges X and Y of 6 μC and 4 μC respectively are separated by a distance of 20 cm.
    (i) Find the location of a point Z between X and Y where the electric field intensity is zero.
    (ii) What is the electric potential at point Z?

12. Two plane parallel conducting plates are held horizontally, one above the other, in a vacuum. Electrons having a speed of 6.0×10^6 ms^{-1} and moving normally to the plates enter the region between them through a hole in the lower plate which is earthed. What potential must be applied to the other plate so that the electrons just fail to reach it? Describe the subsequent motion of these electrons.

13.



Two light, conducting spheres, each of **6 mm** diameter and having a mass of **10 mg**, are suspended from the same point by fine insulating fibers **50 cm** long. Due to electrostatic repulsion, the spheres are in equilibrium when **3 cm** apart. What is;
(i) the force of repulsion between the spheres?
(ii) the charge on each sphere.
(iii) the potential of each sphere.

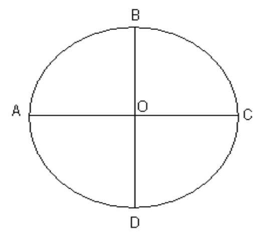
14. A proton is fired from infinity with a speed of **3.7×10^{6} ms^{-1}** towards a stationary charge of **+50e**. Calculate the speed of the proton at a point **1.2×10^{-10}** m from the stationary charge. (Assume mass of proton = **1.67×10^{-27} kg)**

15. Points A and B are 10 cm apart. A point charge of $+3.0 \times 10^{-9}$ C is placed at A and a point charge of -1.0×10^{-9} is placed at B.

(i) X is the point on the straight line through A and B, between A and B, where the electric potential is zero. Calculate the distance AX.

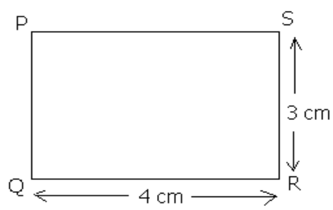
(ii) Show on the diagram, the approximate position of a point Y on the straight line through A and B where the electric field strength is zero. Explain your reasoning.

16.



Charges of + 1.0nC are situated at each of A, B, C and D as shown. Given that AOC = 6m, Calculate the work done in bringing a charge of + 5.0nC from a distant point (infinity) to the centre O.

17.



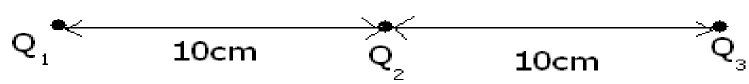
Three point charges of – **3.0×10^{-9} C, +4.0×10^{-9} C and + 3.0×10^{-9} C** are placed in vacuum at the vertices P, Q and R respectively of a rectangle PQRS of sides **3 cm by 4 cm** as shown in the figure above. Calculate the resultant electric field intensity at S.

18. Two point charges X and Y of 6 μC and 4 μC respectively are separated by a distance of 20 cm.

(i) Find the location of a point Z between X and Y where the electric field intensity is zero.

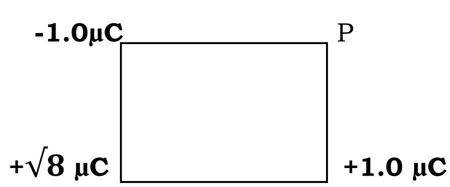
(ii) What is the electric potential at point Z?

19.



Three point charges Q_1, Q_2, and Q_3 of magnitudes +5μC, +6 μC and -20μC respectively are situated along a straight line as shown in the figure above. Calculate the electric field intensity and electric potential at a point mid-way between Q_1 and Q_2.

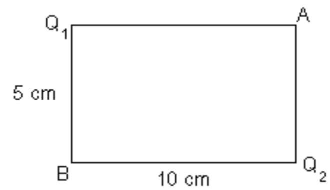
20. Charges of **-1.0μC, +√8 μC and +1.0 μC** are placed at the corners of a square of side **20 cm** as shown below.



Calculate the:
(i) Electric potential at P.

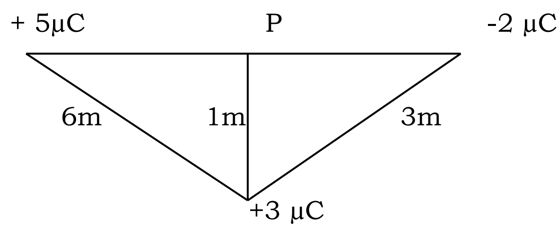
(ii) Electric field intensity at P.

21. Charges **Q_1 and Q_2 of -2.0 μC and +2.0 μC** respectively are placed at two corners of a rectangle of sides 5 cm and 10 cm as shown below.



Calculate:
(i) **Electric potential at A.**
(ii) **Electric field intensity at A.**

22.



Charges are arranged in air as shown in the diagram above. Find the:
(i)Resultant electric field intensity at the point P.
(ii)Work done in moving the **5 μC** to P.

23. In figure 1, points P and Q are at distances 30.0 cm and 20.0 cm from a point charge of 4.0 μC, respectively. Calculate the;
(i) Electric potential difference between P and Q.
(ii) Energy required to bring a charge of +1.0 μC from infinity to point Q.

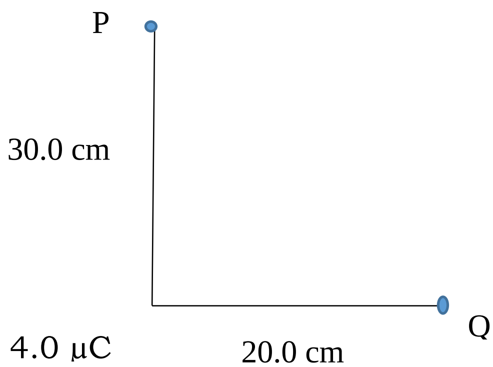


Fig. 1

END