ELECTRIC FIELDS

Akhtar
0333-4281759
SALT Academy

18 Electric fields

18.1 Electric fields and field lines

Candidates should be able to:

1 understand that an electric field is an example of a field of force and define electric field as force per unit positive charge

2 recall and use $F = qE$ for the force on a charge in an electric field

3 represent an electric field by means of field lines

18.2 Uniform electric fields

Candidates should be able to:

1 recall and use $E = \Delta V / \Delta d$ to calculate the field strength of the uniform field between charged parallel plates

2 describe the effect of a uniform electric field on the motion of charged particles

18.3 Electric force between point charges

Candidates should be able to:

1 understand that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its centre

2 recall and use Coulomb's law $F = Q_1Q_2 / (4\pi\varepsilon_0 r^2)$ for the force between two point charges in free space

18.4 Electric field of a point charge

Candidates should be able to:

1 recall and use $E = Q / (4\pi\varepsilon_0 r^2)$ for the electric field strength due to a point charge in free space

18.5 Electric potential

Candidates should be able to:

1 define electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point

2 recall and use the fact that the electric field at a point is equal to the negative of potential gradient at that point

3 use $V = Q / (4\pi\varepsilon_0 r)$ for the electric potential in the field due to a point charge

4 understand how the concept of electric potential leads to the electric potential energy of two point charges and use $E_p = Qq / (4\pi\varepsilon_0 r)$

Electric field:

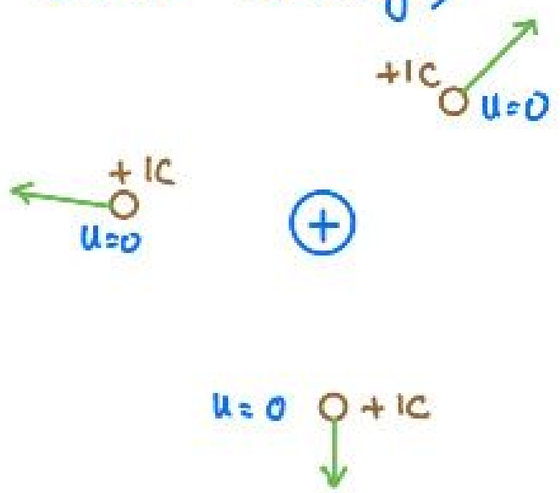
Field $\longrightarrow$ 3D region or space

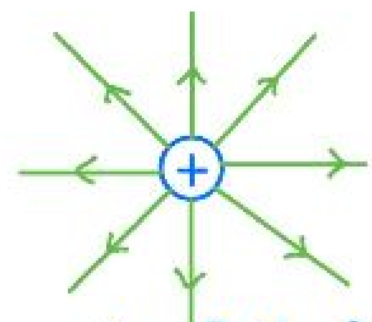
Source $\longrightarrow$ Static charged particle

Detect $\longrightarrow$ another charged particle

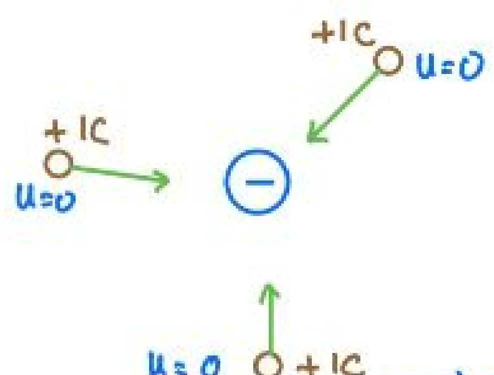
Nature $\longrightarrow$ attractive or repulsive

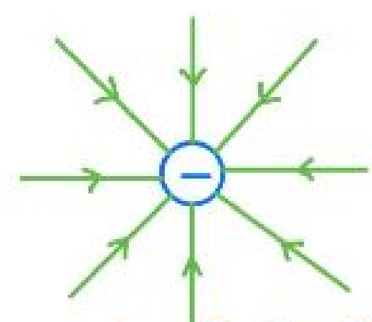
Representation:- Field lines ie each field line represent the force acting on a unit +ve charge (test charge).



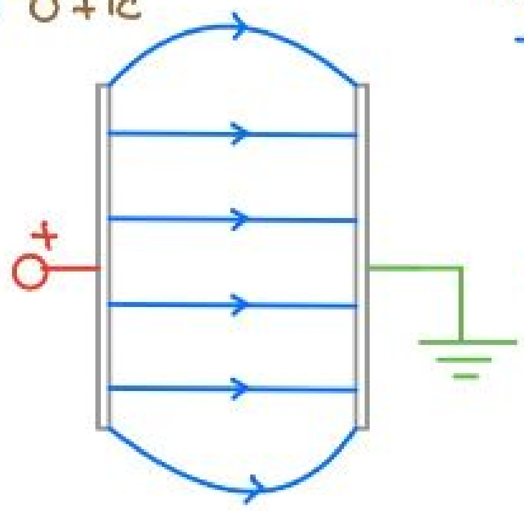


Non-uniform field of isolated +ve charge





Non-uniform field of isolated −ve charge



Uniform field (Separation b/w field lines is constant)

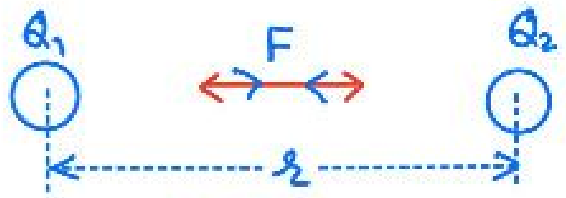
Note: If field lines

(i) orignate from one object and terminate on other object $\longrightarrow$ Attractive field

(ii) only orignate or only terminate at two objects $\longrightarrow$ Repulsive field

Coulomb's Law:-

Mathematical form:



Q_1 and Q_2 are point charges

$$F \propto Q_1 Q_2 \quad \text{.............} \quad (1)$$

$$F \propto \frac{1}{r^2} \quad \text{.............} \quad (2)$$

Combining (1) and (2)

$$F \propto \frac{Q_1 Q_2}{r^2} \Rightarrow \boxed{F = K\frac{Q_1 Q_2}{r^2}}$$

Here $K = \frac{1}{4\pi \varepsilon_0} = \frac{1}{4(3.14)(8.85 \times 10^{-12})} = 8.99 \times 10^{9}\ Nm^2 C^{-2}$

ε_0 - Permittivity of free space/vacuum i.e permission of free space or vacuum to allow electric lines of force to pass through it.

$$\boxed{F = \frac{1}{4\pi \varepsilon_0}\left(\frac{Q_1 Q_2}{r^2}\right)}$$

Statement: The force of attraction or repulsion between two point charges is directly proportional to product of their charges and inversely proportional to the square of separation between their centres.

Q) Calculate the ratio of electric force to Gravitational force between protons in a Helium nucleus (^4_2He)

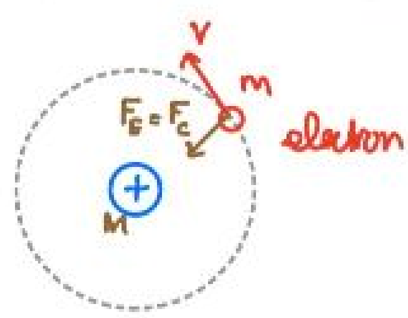
elementary charge	$e = 1.60 \times 10^{-19}$ C
rest mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
	$(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9$ m F$^{-1})$

^4_2He: 4 → no. of nucleons; 2 → No. of proton

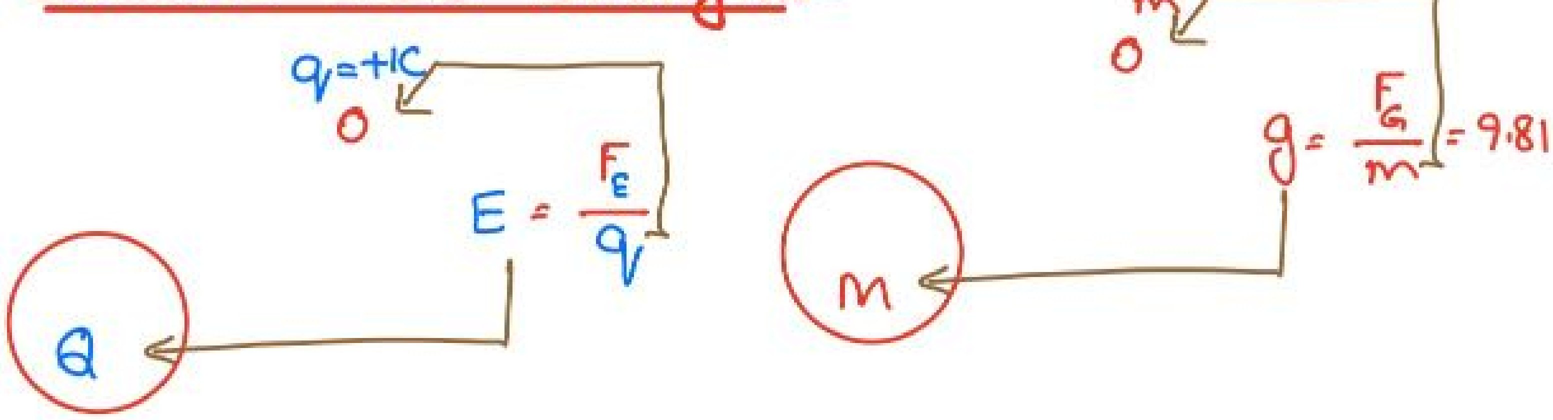
$$\frac{F_E}{F_G} = \frac{K\,\frac{Q_pQ_p}{\cancel{r^2}}}{G\,\frac{m_pm_p}{\cancel{r^2}}} = \frac{K\,(Q_p)^2}{G(m_p)^2} = \frac{(8.99\times10^9)(1.60\times10^{-19})^2}{(6.67\times10^{-11})(1.67\times10^{-27})^2}$$

$$\frac{F_E}{F_G} = 1.24 \times 10^{36}$$

Result: $F_E = 1.24\times10^{36}\,F_G$ i.e Gravitational effects are negligible in comparison to Electri effects in case of an atom.



Electric field strength:-



Def. Electric force per unit +ve charge.

Symbol: E

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

But $F = K\frac{Qq}{r^2}$

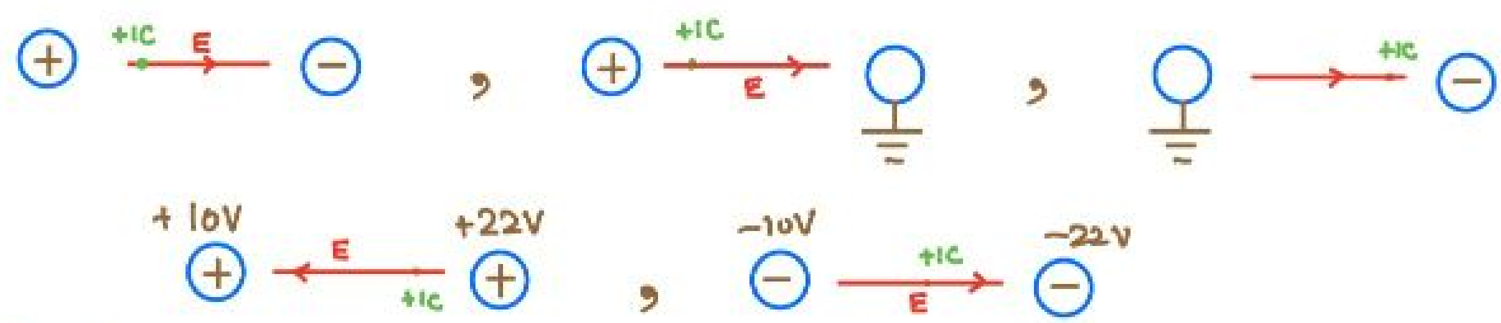
So, $E = \frac{\frac{KQ\cancel{q}}{r^2}}{\cancel{q}} \Rightarrow \boxed{E = \frac{KQ}{r^2}}$

$$\boxed{E = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r^2}\right)}$$

Units: $NC^{-1} = \frac{kg\,m\,s^{-2}}{A\,s} = kg\,m\,A^{-1}s^{-3} = Vm^{-1}$

P.S. Vector

Direction: From high to low potential i.e towards the motion of unit +ve charge or in the direction of force on a unit +ve charge.



Note: $E = K\frac{Q}{r^2}$

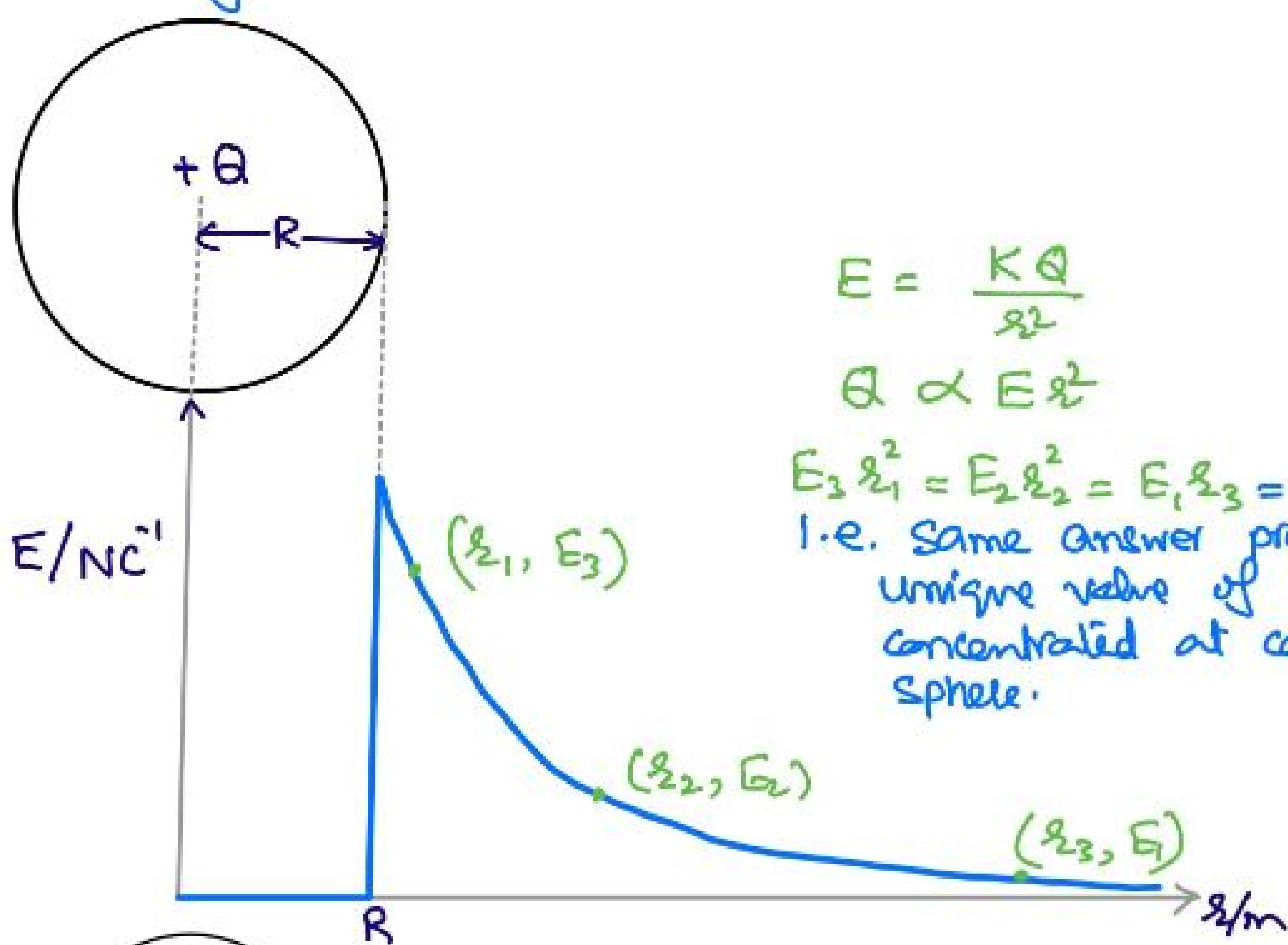
1- $E = +ve$ if $Q = +ve$ {Graph is in 1st quadrant}

2- $E = -ve$ if $Q = -ve$ {Graph is in 4th quadrant}

3- Since there is no charge inside a charged object, so Electric field strength inside the charged object is zero.

4- E = maximum at the surface of charged object/ sphere due to deposition of maximum charge on it.

5- $E \propto \frac{1}{r^2}$ so E/NC^{-1} decreases by following the inverse square relationship when moved away from the surface.

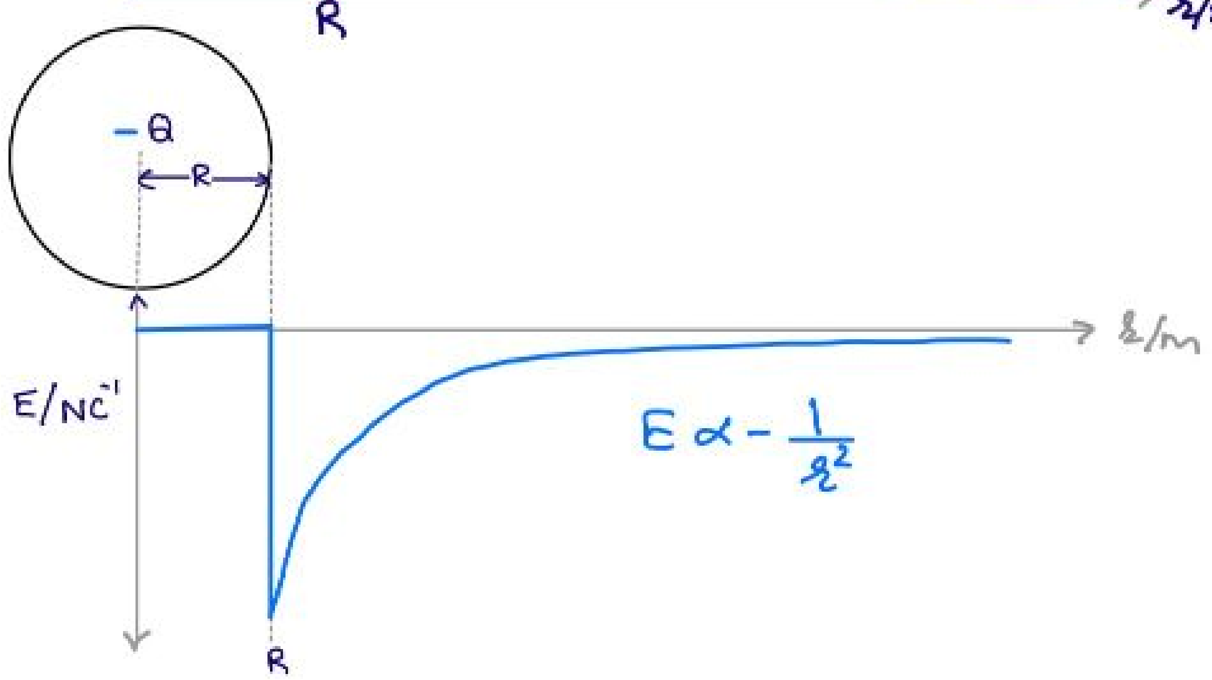


$E = \frac{KQ}{r^2}$

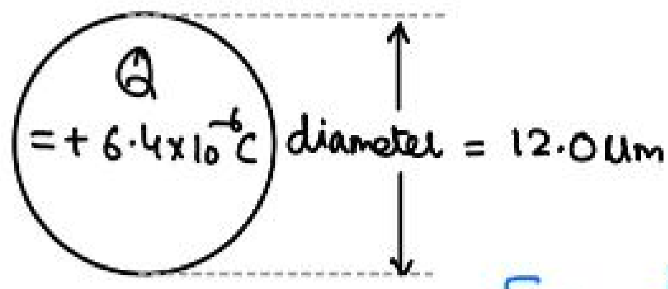
$Q \propto E r^2$

$E_3 r_1^2 = E_2 r_2^2 = E_1 r_3^2 = \text{Same}$

i.e. same answer provide a unique value of charge concentrated at center of sphere.



Q)



Calculate Electric field strength at

(i) surface of sphere

$$E = \frac{KQ}{r^2} = \frac{(8.99\times10^{9})(6.4\times10^{-6})}{(6.0\times10^{-6})^2}$$

$$E = +3.99\times10^{14}\ NC^{-1}$$

(ii) at 24.0 um away from center of sphere.

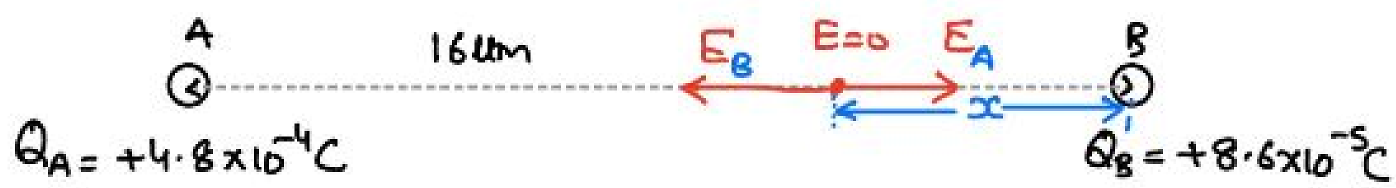
$$E = \frac{KQ}{r^2} = \frac{(8.99\times10^{9})(6.4\times10^{-6})}{(24.0\times10^{-6})^2}$$

$$=$$

(b) State Electric field strength inside the charged sphere.

$E = 0$ as $Q = 0$

Q)



Calculate distance from B at which Electric field strength is zero.

$$E_A = E_B$$

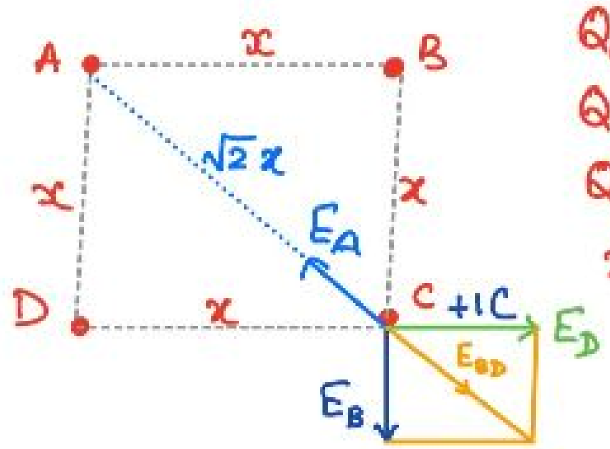
$$\frac{\cancel{K}\,Q_A}{(16\times10^{-6}-x)^2} = \frac{\cancel{K}\,Q_B}{x^2}$$

$$\frac{16\times10^{-6}-x}{x} = \sqrt{\frac{Q_A}{Q_B}}$$

$$\frac{16\times10^{-6}-x}{x} = \sqrt{\frac{4.8\times10^{-4}}{8.6\times10^{-5}}}$$

$$x = 4.76\times10^{-6}\,m$$

Q)



$Q_A = +6.4 \times 10^{-6} C$

$Q_B = +6.4 \times 10^{-6} C$

$Q_D = +6.4 \times 10^{-6} C$

$x = 4.2 \times 10^{-3} m$

Calculate the magnitude of Electric field strength at position C.

$\rightarrow$ $E_B = \dfrac{K Q_B}{r_{BC}} = \dfrac{(8.99 \times 10^{9})(6.4 \times 10^{-6})}{(4.2 \times 10^{-3})^2} = 3.26 \times 10^{9} NC^{-1}$

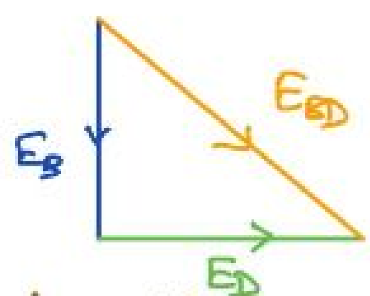
$\rightarrow$ $E_D = \dfrac{K Q_D}{r_{DC}} = \dfrac{(8.99 \times 10^{9})(6.4 \times 10^{-6})}{(4.2 \times 10^{-3})^2} = 3.26 \times 10^{9} NC^{-1}$

$\rightarrow$ $E_A = \dfrac{K Q_A}{r_{AC}} = \dfrac{(8.99 \times 10^{9})(6.4 \times 10^{-6})}{[\sqrt{2}(4.2 \times 10^{-3})]^2} = 1.63 \times 10^{9} NC^{-1}$

$\rightarrow$ $E_{BD} = \sqrt{E_B^2 + E_D^2}$

$= \sqrt{(3.26 \times 10^{9})^2 + (3.26 \times 10^{9})^2}$

$= 4.61 \times 10^{9} NC^{-1}$



$\rightarrow$ Resultant Electric field strength

$E = E_{BD} - E_A$

$= 4.61 \times 10^{9} - 1.63 \times 10^{9}$

$= 2.98 \times 10^{9} NC^{-1}$

Electric potential :-

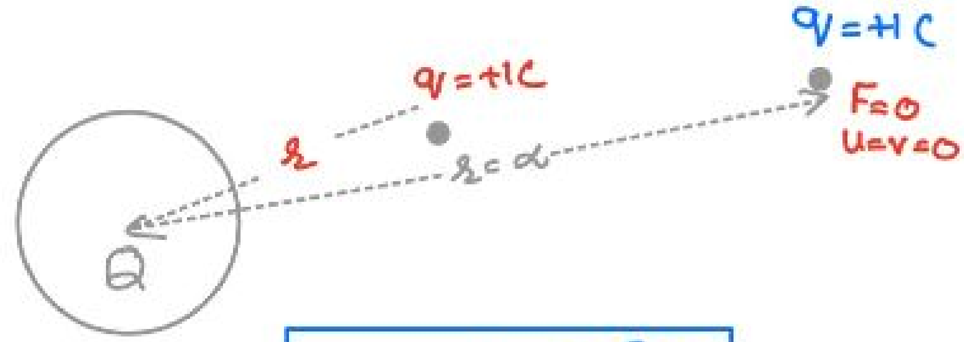
$V = \dfrac{W}{q}$

Def: Amount of work done per unit +ve charge to bring it from infinity up to a point in an electric field.

Symbol : E

Formula :

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



$$V = \frac{KQ}{r} \quad \Rightarrow \quad \boxed{V = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r}\right)}$$

Units: Volt (V)

P.S: Scalar

Note:

1- $V = +ve$ if $Q = +ve$

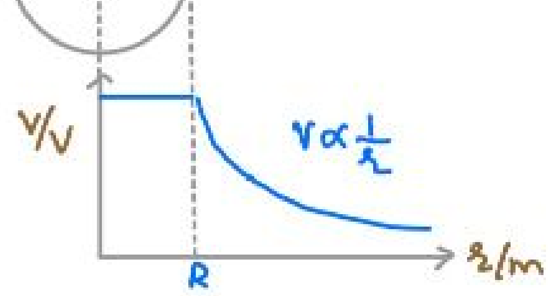
2- $V = -ve$ if $Q = -ve$

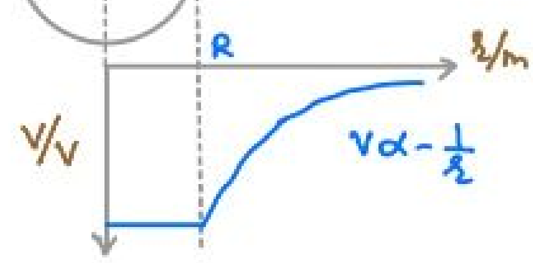
3- $V = \frac{KQ}{r} \Rightarrow Vr = KQ \Rightarrow Q \propto Vr$

i.e if product of V/v and r/m for different respective values of V/V and r/m remain same then this indicates that charge is concentrated at the center of charged object / sphere and is termed as point charged.

4- Potential is defined on the basis of other charges in the field of which a unit +ve charge (test charge) is placed.

Graph:





4 Two point charges A and B each have a charge of $+6.4 \times 10^{-19}$ C. They are separated in a vacuum by a distance of 12.0 μm, as shown in Fig. 4.1.

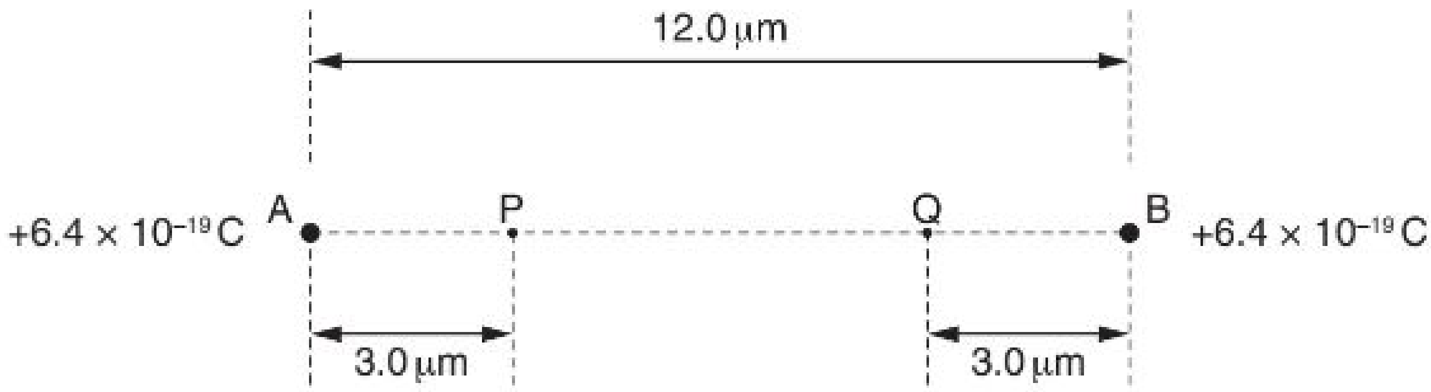


Fig. 4.1

Points P and Q are situated on the line AB. Point P is 3.0 μm from charge A and point Q is 3.0 μm from charge B.

(a) Calculate the force of repulsion between the charges A and B.

$$F = \frac{K Q_A Q_B}{r_{AB}^2}$$

$$= \frac{(8.99 \times 10^{9})(6.4 \times 10^{-19})(6.4 \times 10^{-19})}{(12.0 \times 10^{-6})^2}$$

$$= 2.56 \times 10^{-17}$$

force = ... N [3]

(b) Calculate electric field strength at position

i) P

E_P = Electric field strength due to charge at A − Electric field strength due to charge at B

$$E_P = \frac{K Q_A}{r_{AP}^2} - \frac{K Q_B}{r_{PB}^2}$$

$$= \frac{(8.99 \times 10^{9})(6.4 \times 10^{-19})}{(3.0 \times 10^{-6})^2} - \frac{(8.99 \times 10^{9})(6.4 \times 10^{-19})}{(9.0 \times 10^{-6})^2}$$

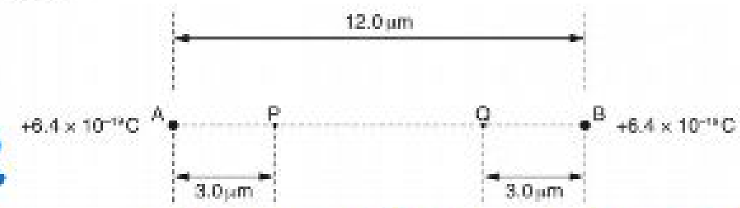
$$= \underline{\qquad\qquad} \ NC^{-1}$$

(ii) Q

Same as at position P because $Q_A = Q_B$, $r_{AP} = r_{QB}$ and $r_{AQ} = r_{PB}$

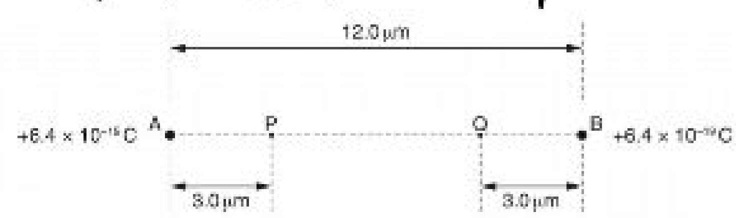
(iii) mid-point of AB

Zero because Electric field strength due to charge at A = electric field strength due to charge at Q but are in opposite directions and cancel out the effect of each other.



(c) Calculate electric potential at point

(i) P



$$V_P = \text{Potential due to charge at A} + \text{Potential due to charge at B}$$

$$= \frac{K\,Q_A}{r_{AP}} + \frac{K\,Q_B}{r_{BP}}$$

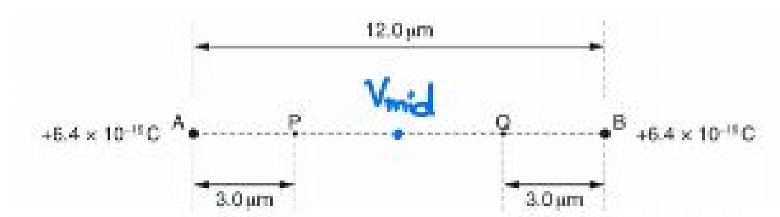
$$= \frac{(8.99\times10^{9})(+6.4\times10^{-19})}{(3.0\times10^{-6})} + \frac{(8.99\times10^{9})(+6.4\times10^{-19})}{(9.0\times10^{-6})}$$

$$V_P = 2.56\times10^{-3}\,V$$

(ii) Point Q

$V_Q = V_P = 2.56\times10^{-3}\,V$ because $Q_A = Q_B$, $r_{AP} = r_{PB}$ and $r_{AQ} = r_{PB}$

(iii) mid-point of AB



$V_P =$ Potential due to charge at A + Potential due to charge at B

$$= \frac{k\,Q_A}{r_{A\text{-mid}}} + \frac{k\,Q_B}{r_{B\text{-mid}}}$$

$$= \frac{(8.99\times10^{9})(+6.4\times10^{-19})}{(6.0\times10^{-6})} + \frac{(8.99\times10^{9})(+6.4\times10^{-19})}{(6.0\times10^{-6})}$$

$$V_P = 1.92\times10^{-3}\,V$$

(d) Explain why, without any calculation, when a small test charge (+1C) is moved from point P to point Q, the net work done is zero.

$V = \frac{W}{q} \Rightarrow W = Vq \Rightarrow W = (V_P - V_Q)(q)$

Since $V_P = V_Q$, so $(V_P - V_Q) = 0$ and $q = +1C$

Therefore, $W = 0$ due to zero p.d. [2]

(e) Calculate the work done by an electron in moving from the midpoint of line AB to point P.

$$V = (V_P - V_{mid})(q)$$

$$V = [(2.56 - 1.92)10^{-3}][1.60\times10^{-19}]$$

$$V = 1.02\times10^{-22}\,J$$

work done = ... J [4]

Q.1

Two positively charged identical metal spheres A and B have their centres separated by a distance of 24 cm, as shown in Fig. 6.1.

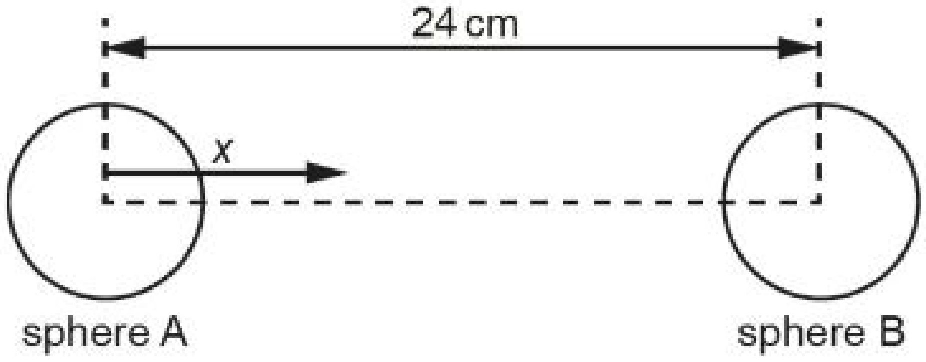


Fig. 6.1 (not to scale)

The variation with distance *x* from the centre of A of the electric field strength *E* due to the two spheres, along the line joining their centres, is represented in Fig. 6.2.

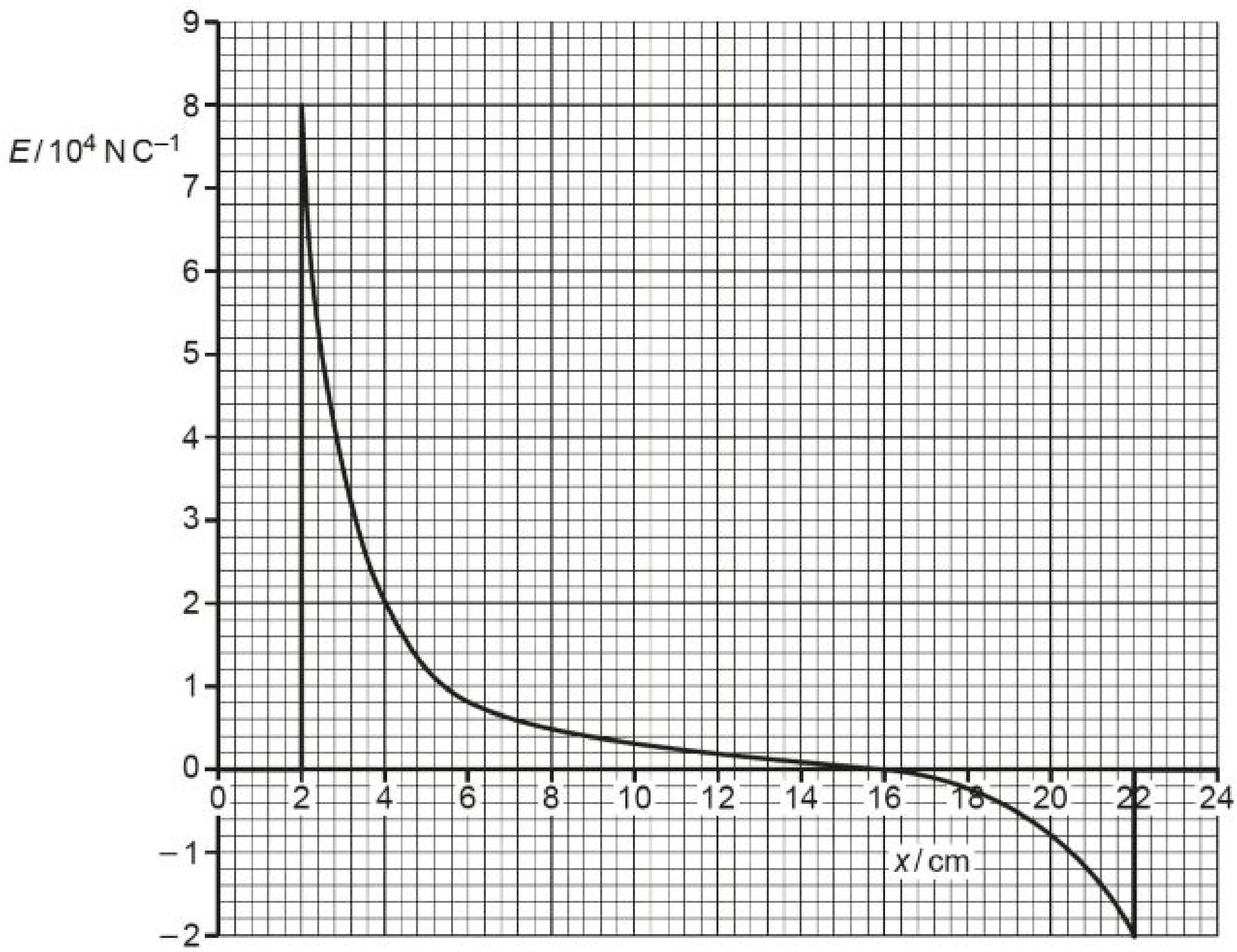


Fig. 6.2

(a) State the radius of the two spheres.

radius = ... cm [1]

(b) The charge on sphere A is 3.6×10^{-9} C. Determine the charge Q_B on sphere B.

Assume that spheres A and B can be treated as point charges at their centres.

Explain your working.

Q_B = ... C [3]

(c) **(i)** Sphere B is removed.

Use information from **(b)** to determine the electric potential on the surface of sphere A.

electric potential = ... V [2]

2.

A metal sphere of radius R is isolated in space.

Point P is a distance x from the centre of the sphere, as illustrated in Fig. 7.1.

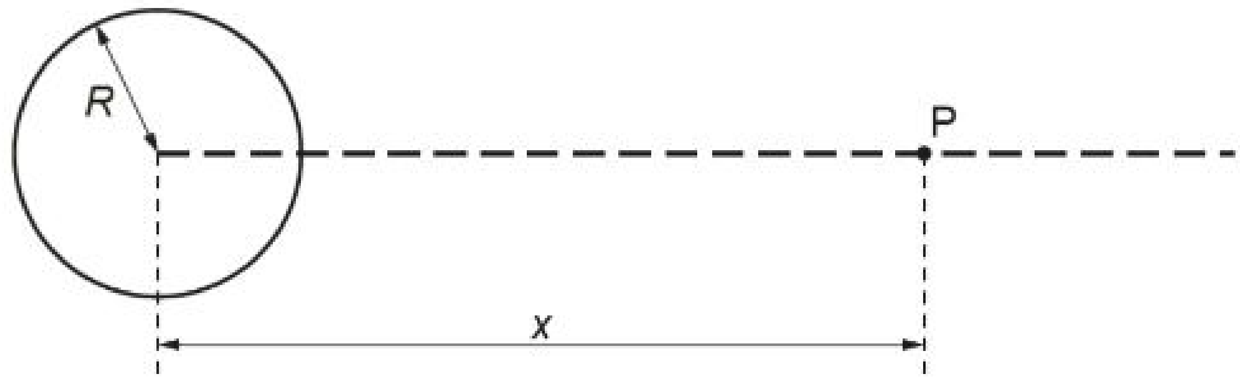


Fig. 7.1

The variation with distance x of the electric field strength E due to the charge on the sphere is shown in Fig. 7.2.

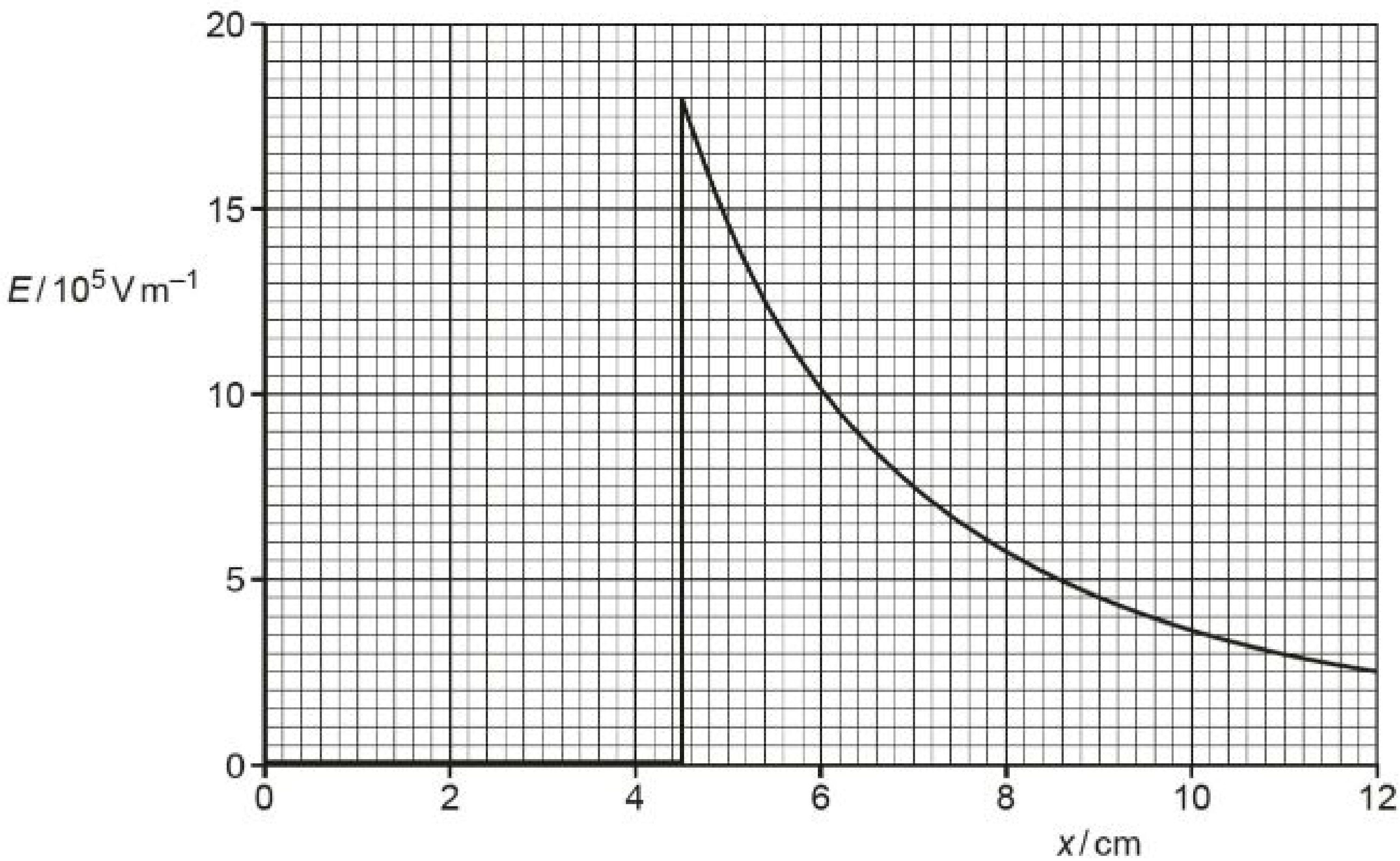


Fig. 7.2

(a) State what is meant by *electric field strength*.

....

....

.... [2]

(b) **(i)** Use Fig. 7.2 to determine the radius R of the sphere. Explain your working.

R = ... cm [2]

(ii) Use Fig. 7.2 to determine the charge Q on the sphere.

Q = ... C [3]

(c) An α-particle is situated a distance 8.0 cm from the centre of the sphere.

Calculate the acceleration of the α-particle.

acceleration = ... $m\,s^{-2}$ [3]

[Total: 10]

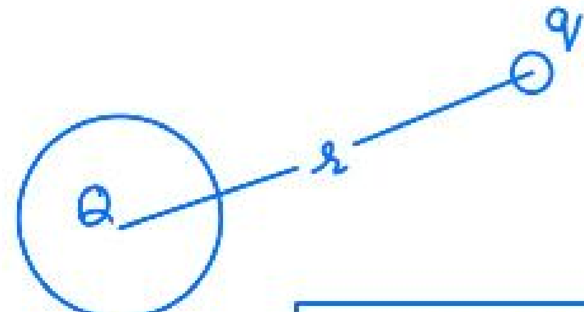
Electric potential energy:-

Field of force — Position — Ability of a charged particle to do work

Def Ability of a charged particle to do work due to change of its position in the field of another charged particle.

Symbol: E_p or EE_p

Formula: $V = \dfrac{W}{q}$



$$\frac{KQ}{r} = \frac{E_P}{q} \Rightarrow E_P = K\frac{Qq}{r} \Rightarrow \boxed{E_P = \frac{1}{4\pi\epsilon_0}\left(\frac{Qq}{r}\right)}$$

Note: $E_p \uparrow$ if work is done against a force

1-

$E_p = \dfrac{K(+Q)(+q)}{r} = +ve$ OR $E_p = \dfrac{K(-Q)(-q)}{r} = +ve$

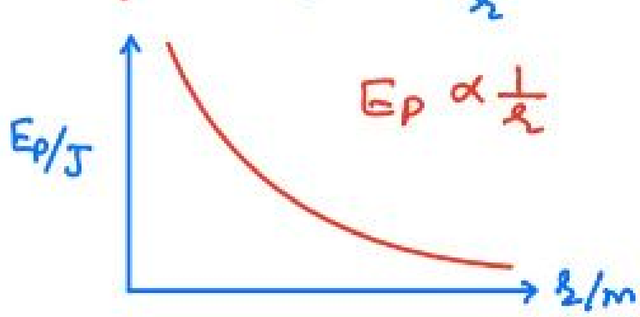
If $(r)\downarrow$, $\left(\dfrac{KQq}{r}\right)\uparrow$ so $E_p\uparrow$

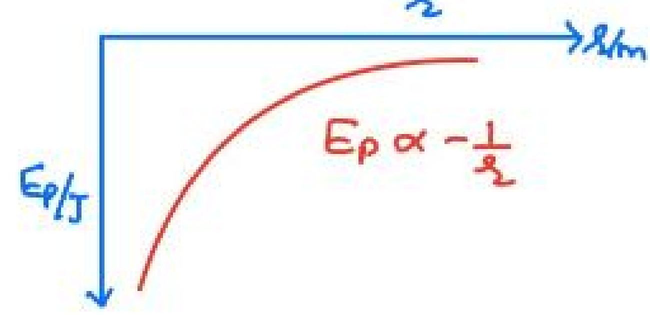
2-

$E_p = \dfrac{K(+Q)(-q)}{r} = -ve$

If $(r)\uparrow$, $\left(\frac{1}{r}\right)\downarrow$, $-\left(\frac{1}{r}\right)\uparrow$, $-\left(\dfrac{KQq}{r}\right)\uparrow$ so $E_p\uparrow$

Graph: $E_p = \dfrac{KQq}{r}$ $\qquad$ $E_p = -K\dfrac{Qq}{r}$



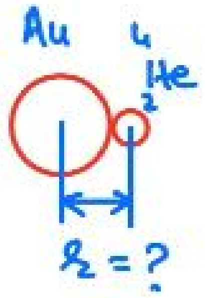


5 An α-particle is travelling in a vacuum towards the centre of a gold nucleus, as illustrated in Fig. 5.1.

Fig. 5.1

The gold nucleus has charge 79e.
The gold nucleus and the α-particle may be assumed to behave as point charges.
At a large distance from the gold nucleus, the α-particle has energy 7.7×10^{-13} J.

(a) The α-particle does not collide with the gold nucleus. Show that the radius of the gold nucleus must be less than 4.7×10^{-14} m.



Loss of E_K of Alpha particle = Gain in $E E_p$

$$7.7 \times 10^{-13} = \frac{K(Q_{gold})(Q_\alpha)}{r}$$

$$7.7 \times 10^{-13} = \frac{(8.99 \times 10^{9})[79 \times 1.60 \times 10^{-19}][2 \times 1.60 \times 10^{-19}]}{r}$$

$$r = 4.72 \times 10^{-14} m$$

This value of 'r' is the separation of closest approach of Alpha particle from Gold nucleus, so radius of Gold nucleus must be less than 4.72×10^{-14} m [3]

(b) Determine the acceleration of the α-particle for a separation of 4.7×10^{-14} m between the centres of the gold nucleus and of the α-particle.

$$F = m a$$

$$\frac{K(Q_{gold})(Q_\alpha)}{r^2} = (m_\alpha)(a)$$

$$\frac{(8.99 \times 10^{9})[79(1.60 \times 10^{-19})][2(1.60 \times 10^{-19})]}{(4.7 \times 10^{-14})^2} = [4(1.66 \times 10^{-27})][a]$$

acceleration = ... ms^{-2} [3]

(c) In an α-particle scattering experiment, the beam of α-particles is incident on a very thin gold foil.
Suggest why the gold foil must be very thin.

Single deflection of α-particle from Gold nucleus can be result about size and mass of nucleus [1]

[Total: 7]

For Examiner's Use

5 Two deuterium (^2_1H) nuclei are travelling directly towards one another. When their separation is large compared with their diameters, they each have speed v as illustrated in Fig. 5.1.

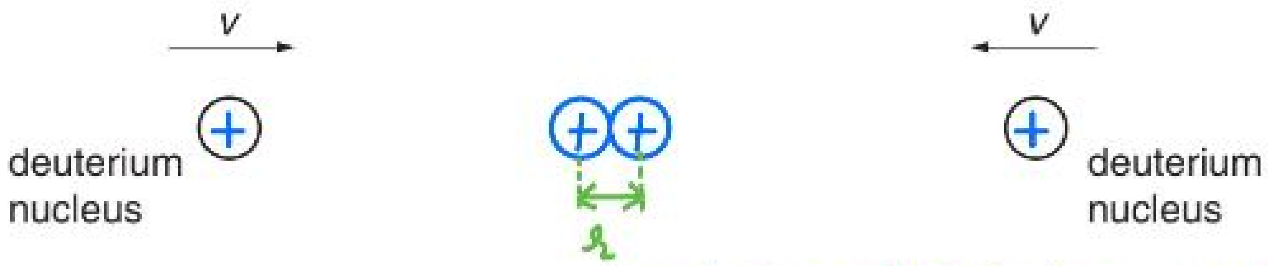


Fig. 5.1 → Separation between nuclei is equal to the diameter of a nucleus

The diameter of a deuterium nucleus is 1.1×10^{-14} m.

(a) Use energy considerations to show that the initial speed v of the deuterium nuclei must be approximately $2.5 \times 10^6\,\mathrm{m\,s^{-1}}$ in order that they may come into contact. Explain your working.

Loss of Kinetic energy = Gain in Electric E_p

$$\cancel{2}\left(\frac{1}{\cancel{2}} m v^2\right) = \frac{1}{4\pi\varepsilon_0}\left[\frac{QQ}{r}\right]$$

$$\left[2\left(1.66\times10^{-27}\right)\right]v^2 = \left[\frac{1}{4(3.14)(8.85\times10^{-12})}\right]\left[\frac{(1.60\times10^{-19})^2}{1.1\times10^{-14}}\right]$$

[3]

4 **(a)** Explain what is meant by the *potential energy* of a body.

The ability of a body to do work due to change of its position in a field of force. [2]

(b) Two deuterium (^2_1H) nuclei each have initial kinetic energy E_K and are initially separated by a large distance.

The nuclei may be considered to be spheres of diameter 3.8×10^{-15} m with their masses and charges concentrated at their centres.

The nuclei move from their initial positions to their final position of just touching, as illustrated in Fig. 4.1.

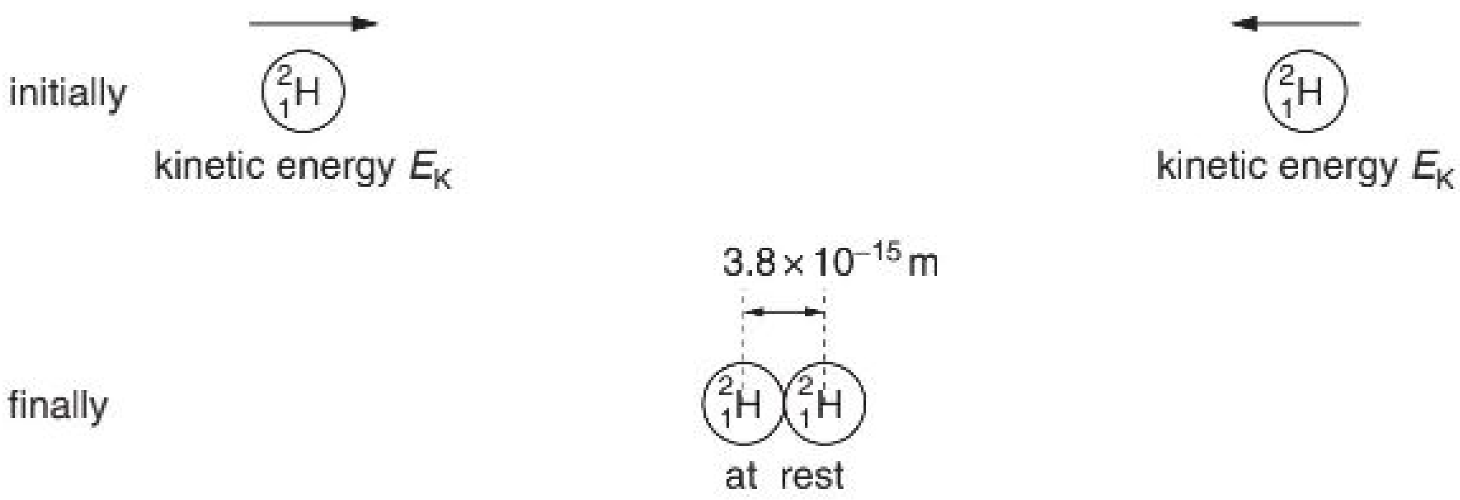


Fig. 4.1

(i) For the two nuclei approaching each other, calculate the total change in

1. gravitational potential energy,

$$G E_p = -\frac{GMm}{r}$$

$$= -\frac{(6.67\times10^{-11})[2(1.66\times10^{-27})][2(1.66\times10^{-27})]}{3.8\times10^{-15}}$$

$$= -1.93\times10^{-49}$$

energy = 1.93×10^{-49} J [3]

2. electric potential energy.

$$E E_p = \frac{1}{4\pi\varepsilon_0}\left(\frac{Qq}{r}\right)$$

$$= \frac{(8.99\times10^{9})(1.60\times10^{-19})(1.60\times10^{-19})}{3.8\times10^{-15}}$$

$$= 6.06\times10^{-14}$$

energy = 6.06×10^{-14} J [3]

(ii) Use your answers in **(i)** to show that the initial kinetic energy E_K of each nucleus is 0.19 MeV.

Kinetic energy of both nuclei = Gain in Electric E_p + Loss of Gravitational E_p

$2E_K = EE_p - GE_p$

$2E_K = 6.06\times10^{-14} - 1.93\times10^{-49}$

$E_K = 3.03\times10^{-14}$ J

$1\text{ MeV} = (10^6)(1.60\times10^{-19}) = 1.60\times10^{-13}$ J

$E_K = \frac{3.03\times10^{-14}}{1.60\times10^{-13}} = 0.19$ MeV

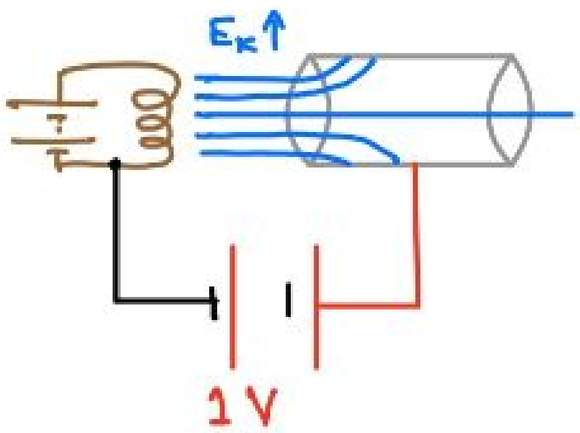
[2]

(iii) The two nuclei may rebound from each other. Suggest one other effect that could happen to the two nuclei if the initial kinetic energy of each nucleus is greater than that calculated in **(ii)**.

Both nuclei may fuse each other as in nuclear Fusion reaction to form a heavy nucleus. [1]

Electron volt: It is the Kinetic energy gained by an electron which is accelerated through a p.d. of 1 volt.

$E = I^2 R t$



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

$QV = W$

$(1e)(1V) = 1.60\times10^{-19}$ J

$\boxed{1\text{ eV} = 1.60\times10^{-19}\text{ J}}$

$1\text{ MeV} = (10^6)(1.60\times10^{-19})$

$1\text{ MeV} = 1.60\times10^{-13}$ J

5 Two small solid metal spheres A and B have equal radii and are in a vacuum. Their centres are 15 cm apart.
Sphere A has charge +3.0 pC and sphere B has charge +12 pC. The arrangement is illustrated in Fig. 5.1.

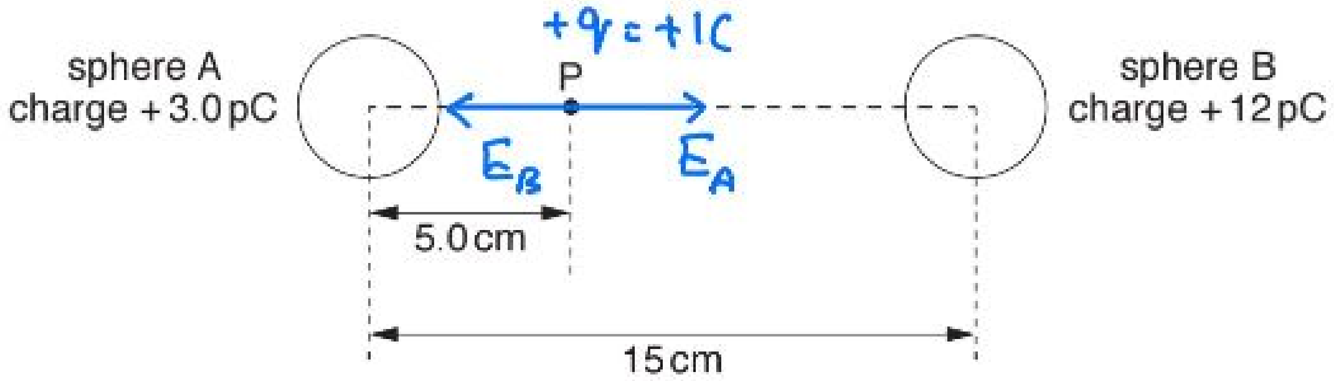


Fig. 5.1

Point P lies on the line joining the centres of the spheres and is a distance of 5.0 cm from the centre of sphere A.

(a) Suggest why the electric field strength in both spheres is zero.

Since charged particles are at rest, so Electric Force becomes zero and so is the Electric field strength by $E = \frac{F}{q} = \frac{0}{q} = 0$ [2]

(b) Show that the electric field strength is zero at point P. Explain your working.

Electric field strength at P due to charge at A:

$$E_A = \frac{K\,Q_A}{r_A^2} = \frac{(8.99\times10^{9})(3.0\times10^{-12})}{(5.0\times10^{-2})^2} = 10.788 = 10.8\,NC^{-1}$$

Electric field strength at P due to charge at :

$$E_B = \frac{K\,Q_B}{r_B^2} = \frac{(8.99\times10^{9})(12\times10^{-12})}{(10\times10^{-2})^2} = 10.788 = 10.8\,NC^{-1}$$

Since $E_A = E_B$ in magnitude but act in opposite directions and cancel out the effect of each other. [3]

(c) Calculate the electric potential at point P.

$$V_P = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_A}{r_A}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_B}{r_B}\right)$$

$$= (8.99\times10^{9})\left[\frac{3.0\times10^{-12}}{5.0\times10^{-2}} + \frac{12\times10^{-12}}{10\times10^{-2}}\right]$$

$$= 1.6182$$

electric potential = 1.62 V [2]

(d) A silver-107 nucleus ($^{107}_{47}Ag$) has speed v when it is a long distance from point P.

Use your answer in **(c)** to calculate the minimum value of speed v such that the nucleus can reach point P.

$$E_K = E_P$$

$$\frac{1}{2}mv^2 = Vq \Rightarrow v = \sqrt{\frac{2Vq}{m}}$$

$$v = \sqrt{\frac{2(1.62)[47(1.60\times10^{-19})]}{107(1.66\times10^{-27})}}$$

$$v = 1.17\times10^4$$

speed = 1.17×10^4 m s^{-1} [3]

[Total: 10]

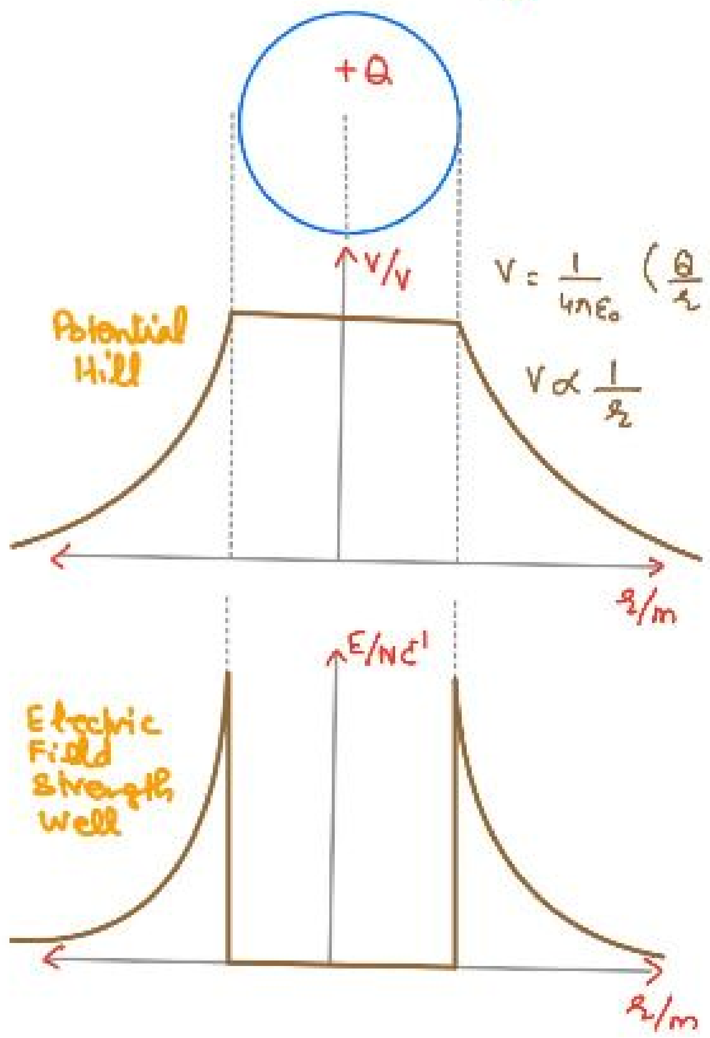
RELATION BETWEEN ELECTRIC FIELD AT A POINT AND POTENTIAL GRADIENT:-

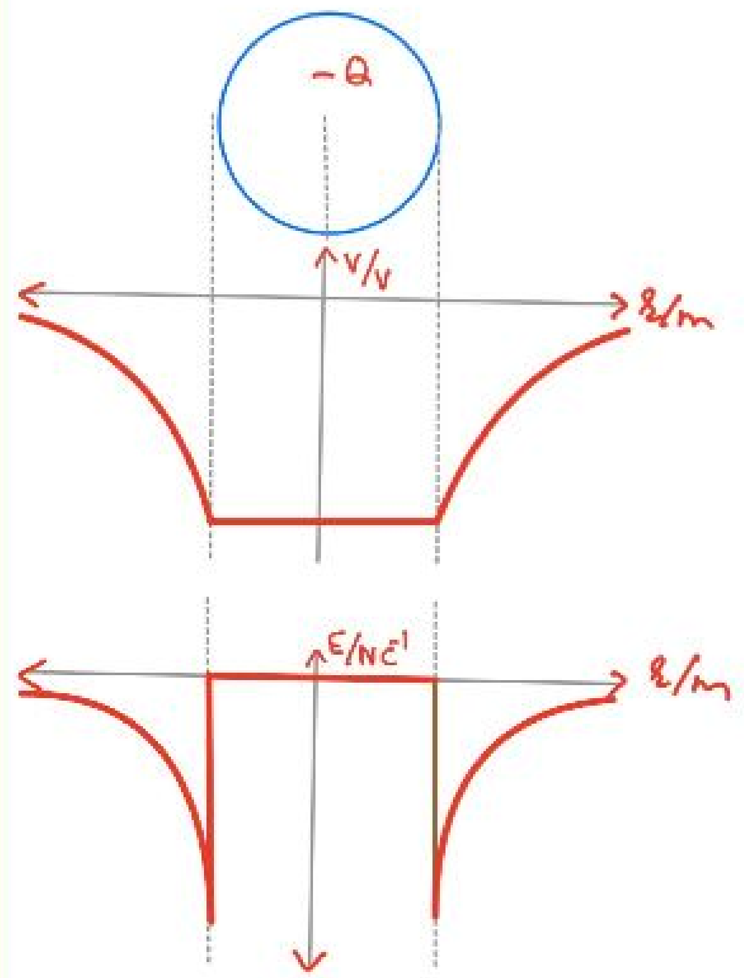
Electric field strength at a point is equal to -ve potential gradient.

E = -ve Gradient of potential against distance graph

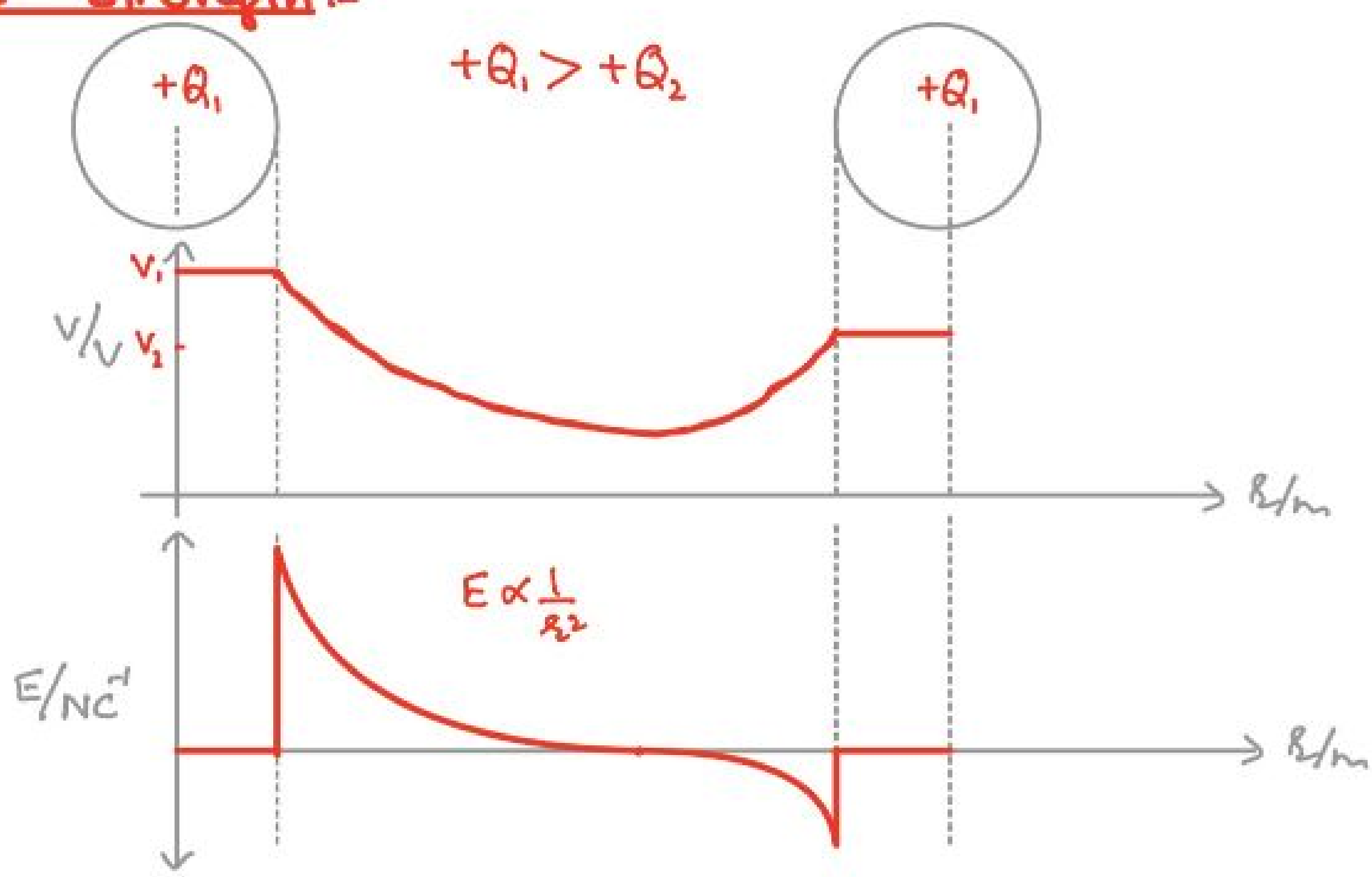
$$E = -\frac{\Delta V}{\Delta d}$$

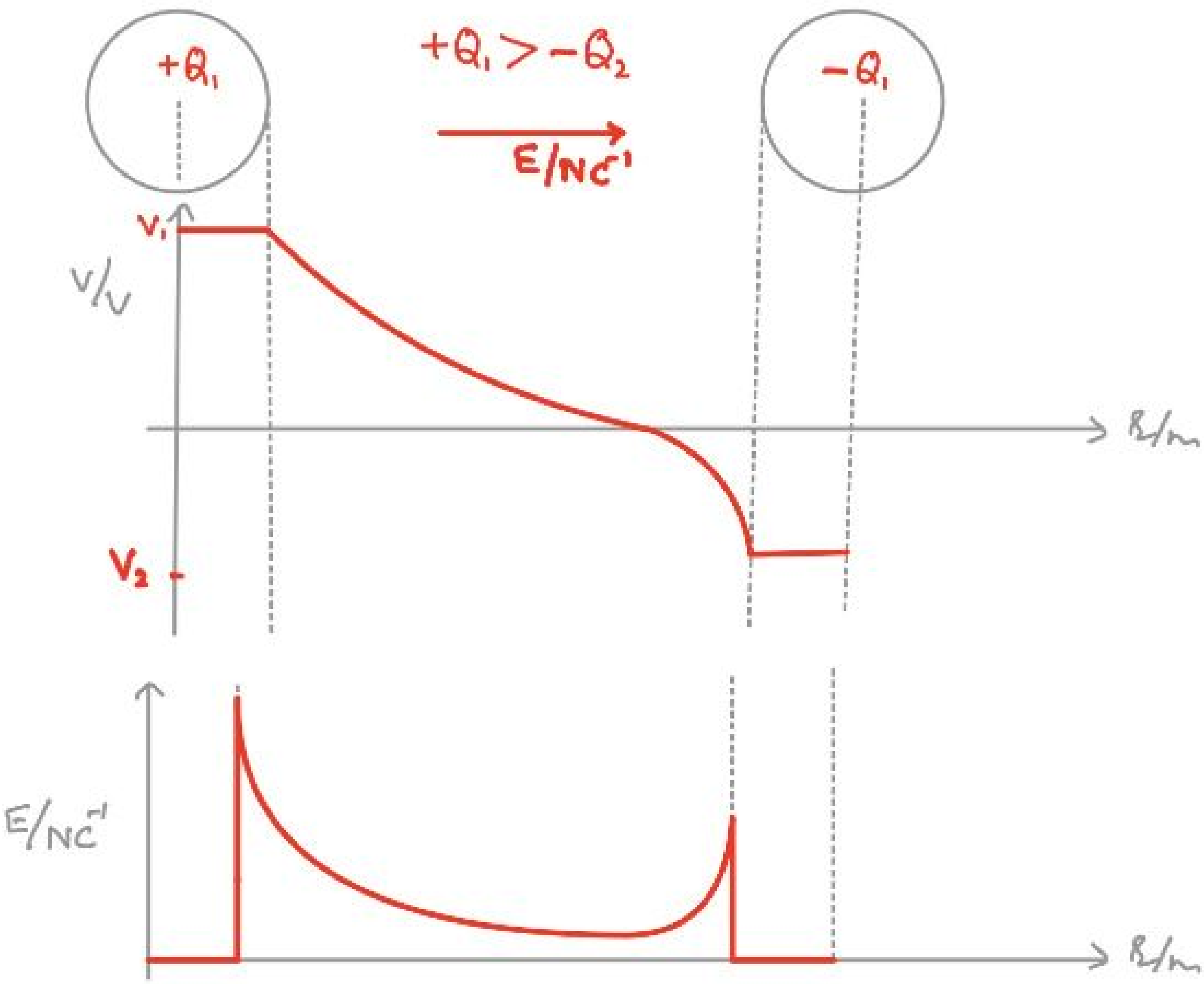
Isolated charge:





Graph of Electric potential and Electric Field strength:-





Note: Point at which
E/NC^{-1} = Max and/or V/V = max
and this provides radius of the conductor/ sphere.

6 A solid metal sphere of radius R is isolated in space. The sphere is positively charged so that the electric potential at its surface is V_S. The electric field strength at the surface is E_S.

(a) On the axes of Fig. 6.1, show the variation of the electric potential with distance x from the centre of the sphere for values of x from $x = 0$ to $x = 3R$.

$V = \frac{KQ}{r}$

$V \propto \frac{1}{r}$

r	R	2R	3R
V	$1.0V_s$	$0.5V_s$	$0.33V_s$

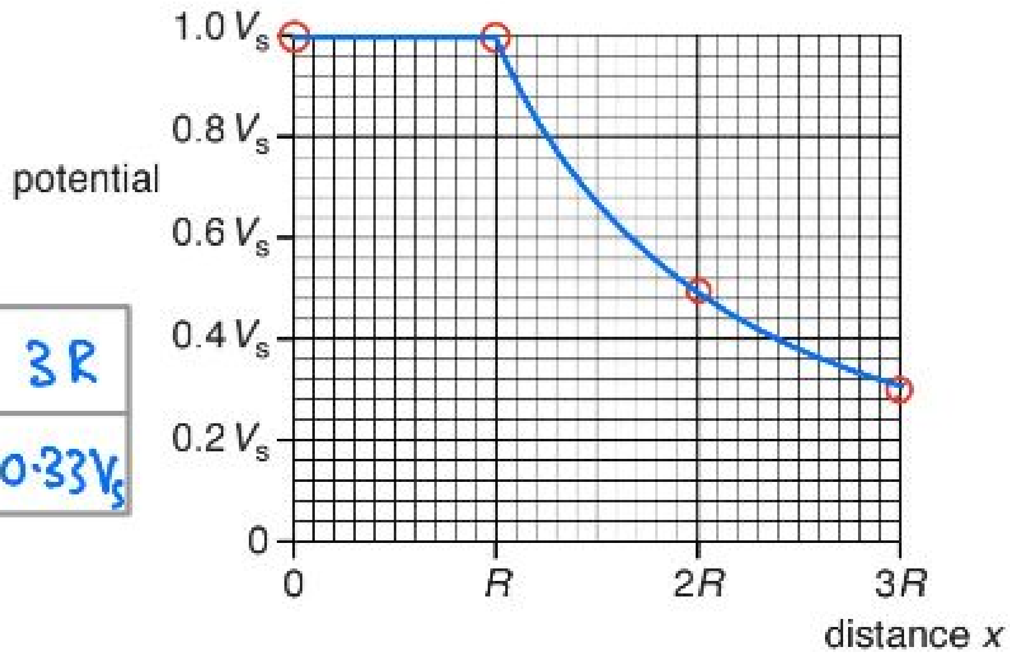
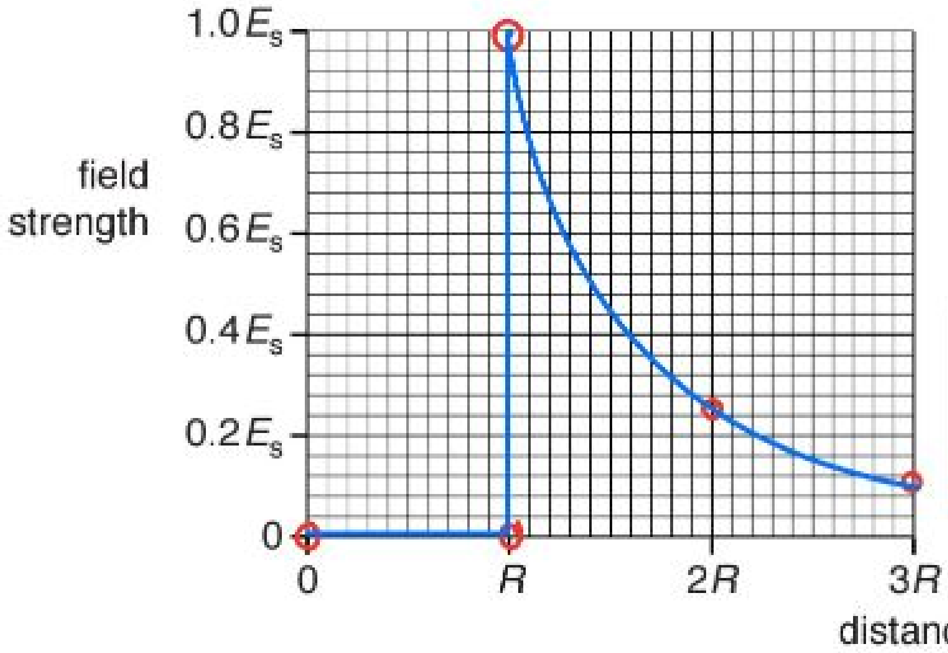


Fig. 6.1

[3]

(b) On the axes of Fig. 6.2, show the variation of the electric field strength with distance x from the centre of the sphere for values of x from $x = 0$ to $x = 3R$.

$E = -\frac{\Delta V}{\Delta x}$



$E = \frac{KQ}{r^2}$

$E \propto \frac{1}{r^2}$

r	R	2R	3R
E	$1.0E_s$	$0.25E_s$	$0.11E_s$

Fig. 6.2

[3]

[Total: 6]

6 **(a)** State an expression for the electric field strength E at a distance r from a point charge Q in a vacuum.
State the name of any other symbol used.

$E = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r^2}\right)$

ε_0 – Permittivity of free space [2]

(b) Two point charges A and B are situated a distance 10.0 cm apart in a vacuum, as illustrated in Fig. 6.1.

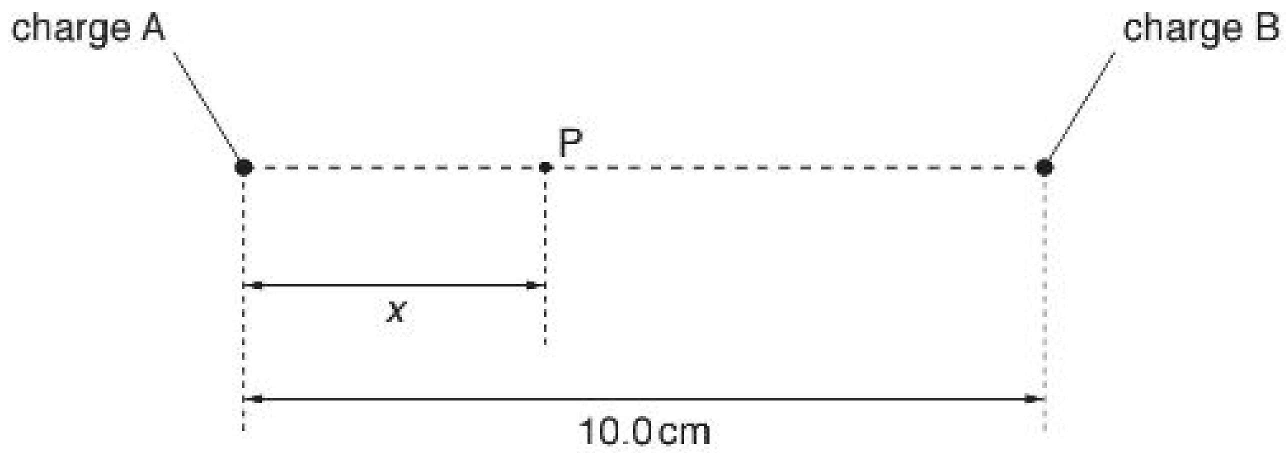


Fig. 6.1

A point P lies on the line joining the charges A and B. Point P is a distance x from A.

The variation with distance x of the electric field strength E at point P is shown in Fig. 6.2.

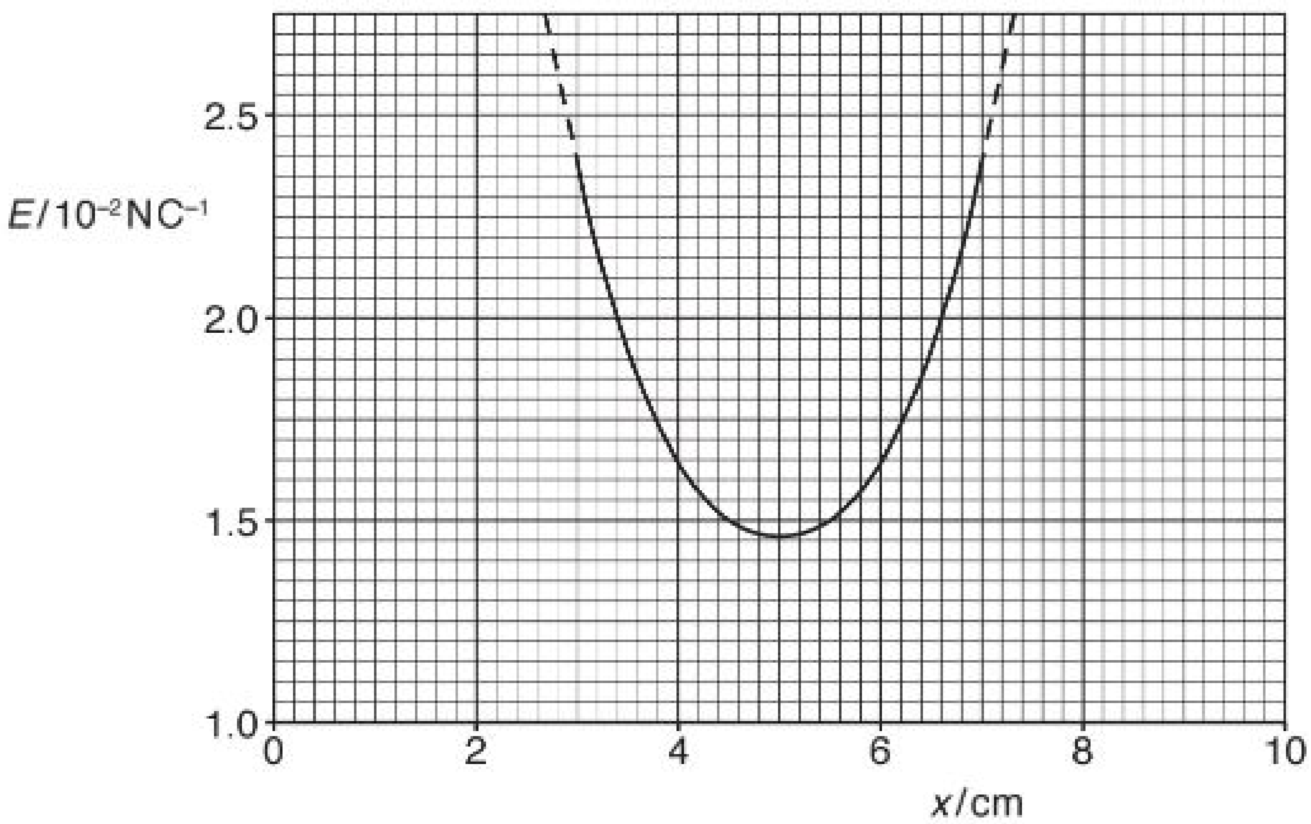


Fig. 6.2

State and explain whether the charges A and B:

(i) have the same, or opposite, signs

Opposite signs because Electric field strength graph remain in first quadrant and is not zero at any position.

[2]

(ii) have the same, or different, magnitudes.

At 5.0cm, Electric field strength is minimum and 5.0cm is equi-distant from each charge so Electric field strength has same magnitudes.

[2]

(c) An electron is situated at point P.

Without calculation, state and explain the variation in the magnitude of the acceleration of the electron as it moves from the position where $x = 3\,\text{cm}$ to the position where $x = 7\,\text{cm}$.

Since $F = Eq$

$ma = Eq \Rightarrow a = \left(\frac{q}{m}\right)E \Rightarrow a \propto E$

From 3.0cm to 5.0cm → acceleration decreases

At 5.0cm → acceleration is minimum

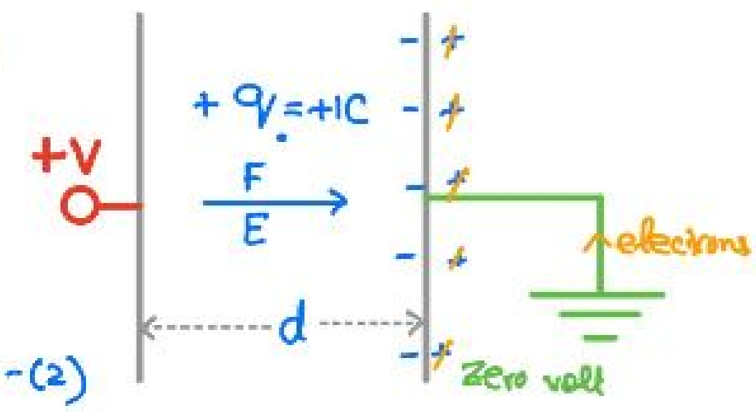
From 5.0cm to 7.0cm → acceleration increases

[4]

[Total: 10]

Uniform Electric Field strength:- Electric field is uniform between two parallel plates and is represented by equi-distant parallel lines directed from high to low potential

$$E = \frac{F}{q} \quad \text{--------} (1)$$



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

$$V = \frac{Fd}{q} \Rightarrow V = \left(\frac{F}{q}\right)(d) \quad \text{-----} (2)$$

Put 1 into eq. (2)

$$V = Ed \quad \Rightarrow \quad E = \frac{V}{d} \Rightarrow \boxed{E = \frac{\Delta V}{\Delta d}}$$

Here, ΔV - P.d b/w parallel plates
Δd - Separation between parallel plates

Force on a charged particle in a uniform E-field:-

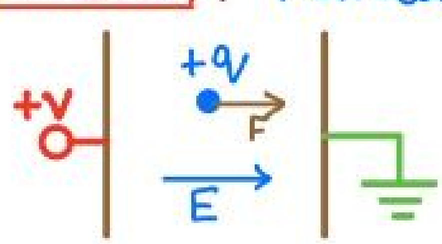
Since, $E = \frac{F}{q}$ --------- (1)

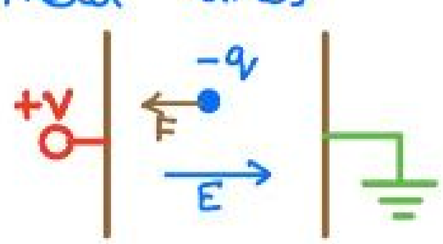
Also $E = \frac{V}{d}$ ------- (2)

From (1) and (2)

$$\frac{F}{q} = \frac{V}{d} \Rightarrow \boxed{F = \frac{Vq}{d}}$$

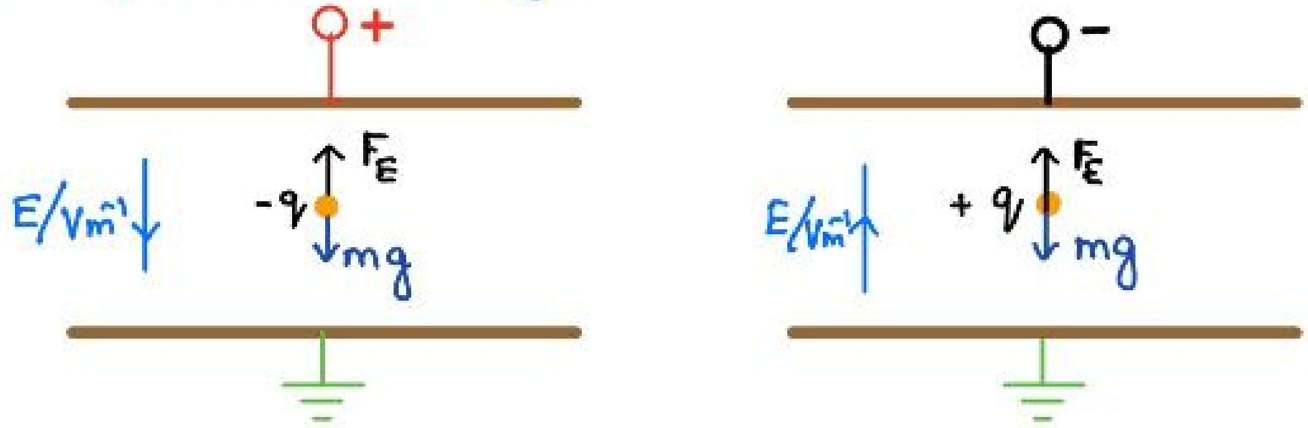
Direction: Parallel to field lines





Determination of specific charge:-

charge to mass ratio of a particle is the specific charge.



Expression: If a charged particle is at rest in a mutual parallel Electric and Gravitational fields. So in equilibrium state

upward Electric force = Downward weight

$$Eq = mg$$

$$\boxed{\frac{q}{m} = \frac{g}{E}}$$

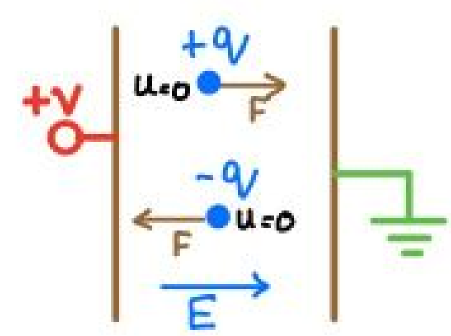
Also, for a uniform E-field, $E = \frac{V}{d}$

$$\frac{q}{m} = \frac{g}{\frac{V}{d}} \Rightarrow \boxed{\frac{q}{m} = \frac{gd}{V}}$$

Speed of a charged particle in a uniform E-field:-

By Principle of conservation of energy

Loss of Electric E_p = Gain in E_K



$$Vq = \frac{1}{2}mv^2$$

$$\boxed{v = \sqrt{\frac{2Vq}{m}}}$$

Q) Calculate the kinetic energy gained by an electron which is accelerated through a p.d. of 100V.

By conservation of energy

Gain in E_K = Loss of Electric E_P

$$E_K = Vq$$

$$= (100)(1.60 \times 10^{-19}) = 1.60 \times 10^{-17} J$$

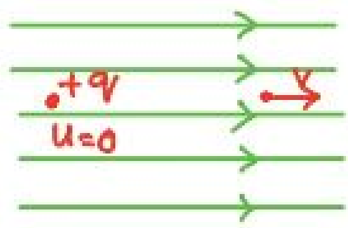
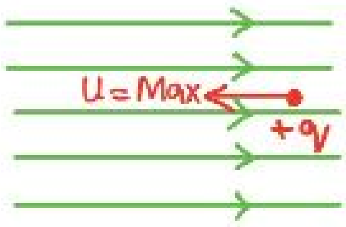
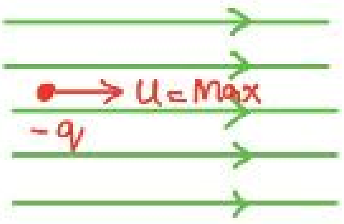
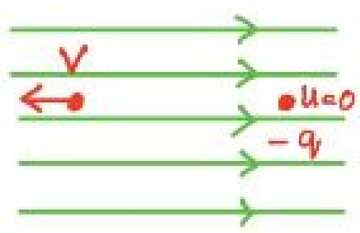
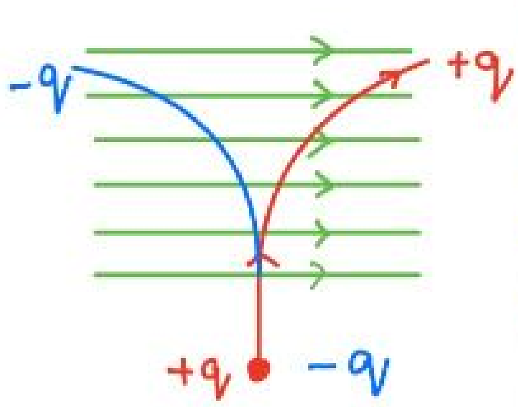
(b) Calculate final velocity of this electron.

$$E_K = \frac{1}{2} m v^2$$

$$1.60 \times 10^{-17} = \frac{1}{2} (9.11 \times 10^{-31}) v^2$$

$$v = \underline{\qquad\qquad} m s^{-1}$$

Path of a charged particle in a Uniform E-field:-

S.No	Diagram	Path	Accelerate	ΔE_k	ΔE_p
1		straight line	uniform acceleration	$\uparrow$	$\downarrow$
2		straight line	uniform deceleration	$\downarrow$	$\uparrow$
3		straight line	uniform deceleration	$\downarrow$	$\uparrow$
4		straight line	uniform acceleration	$\uparrow$	$\downarrow$
5		curved path and charges come closer to oppositely charged plates	uniform acceleration	$\uparrow$	$\downarrow$

Akhtar Mahmood (0333-4281759)
M.Sc.(Physics), MCS, MBA-IT, B.Ed.
MIS, DCE, D AS/400e(IBM), OCP(PITB)
teacher_786@hotmail.com

STATIC ELECTRICITY

1. Two parallel metal plates P and Q are situated 8.0 cm apart in air, as shown in Fig. 1.1.

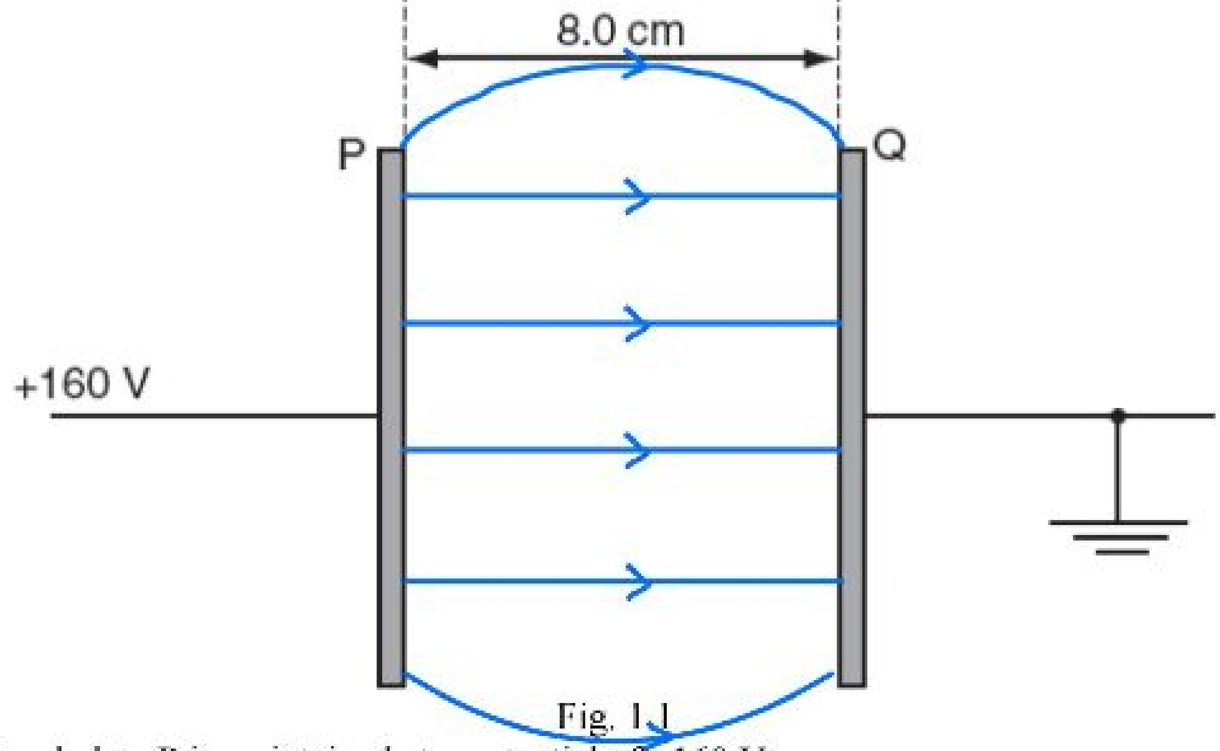


Fig. 1.1

Plate Q is earthed and plate P is maintained at a potential of +160 V.

(a) **(i)** On Fig. 1.1, draw lines to represent the electric field in the region between the plates. [2]

(ii) Show that the magnitude of the electric field between the plates is 2.0×10^3 Vm^{-1}.

$$E = \frac{\Delta V}{\Delta d} \Rightarrow E = \frac{160 - 0}{8.0 \times 10^{-2}} = 2.0 \times 10^{3}\ Vm^{-1}$$

[1]

(b) A dust particle is suspended in the air between the plates. The particle has charges of $+1.2 \times 10^{-15}$C and -1.2×10^{-15} C near its ends. The charges may be considered to be point charges separated by a distance of 2.5 mm, as shown in Fig. 1.2.

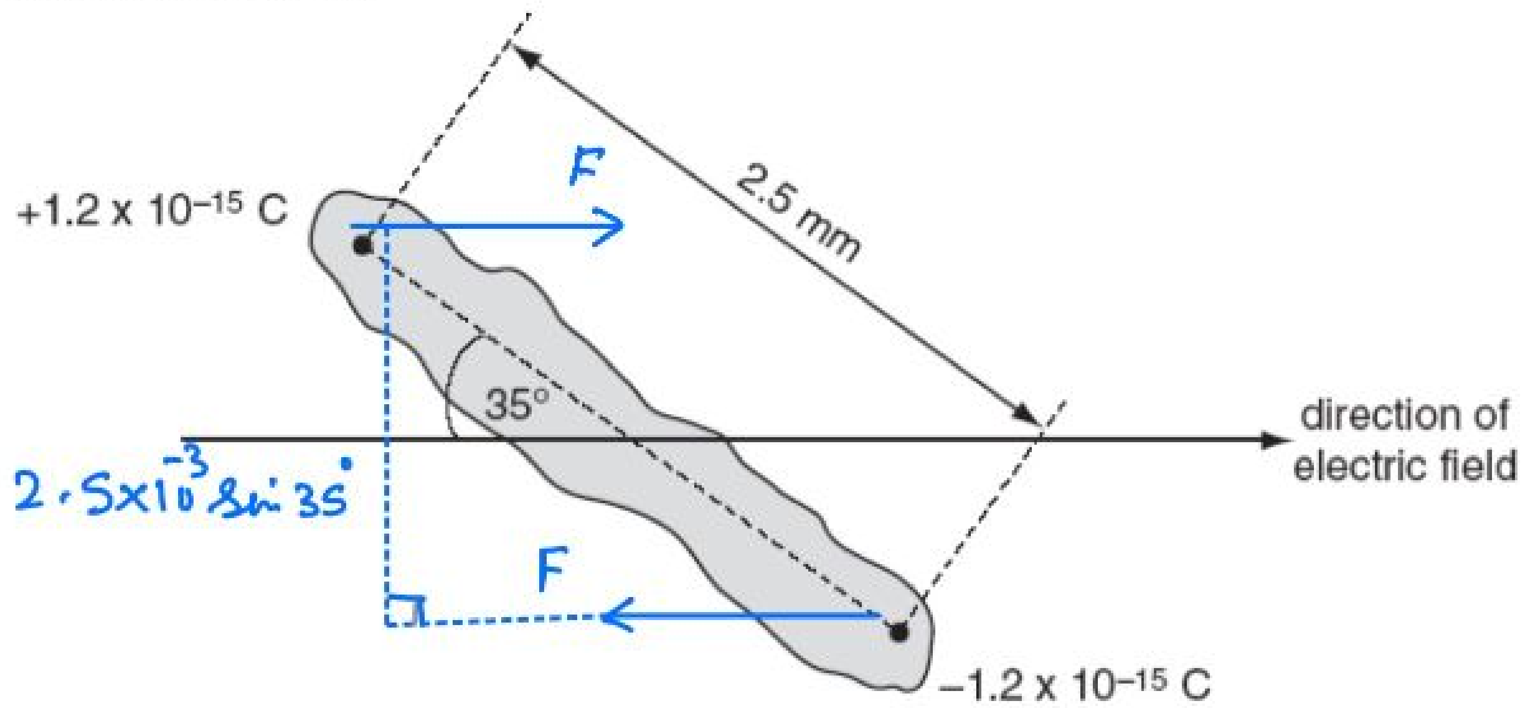


Fig. 1.2

The particle makes an angle of 35° with the direction of the electric field.

(i) On Fig. 1.2, draw arrows to show the direction of the force on each charge due to the electric field. [1]

(ii) Calculate the magnitude of the force on each charge due to the electric field.

$$F = Eq$$
$$= (2.0 \times 10^{3})(1.2 \times 10^{-15})$$

force = 2.4×10^{-12} N [2]

(iii) Determine the magnitude of the couple acting on the particle.

Clockwise torque of a couple $= (F)(d)$
$= (2.4 \times 10^{-12})(2.5 \times 10^{-3} \sin 35^\circ)$

couple = ... Nm [2]

(iv) Suggest the subsequent motion of the particle in the electric field.

Dust particle move in clockwise direction and charges come closer to oppositely charged plates. [2]

2. Two horizontal metal plates X and Y are at a distance 0.75 cm apart. A positively charged particle of mass 9.6×10^{-15} kg is situated in a vacuum between the plates, as illustrated in Fig. 2.1

Akhtar Mahmood (0333-4281759)
M.Sc.(Physics), MCS, MBA-IT, B.Ed.
MIS, DCE, D AS/400e(IBM), OCP(PITB)
teacher_786@hotmail.com

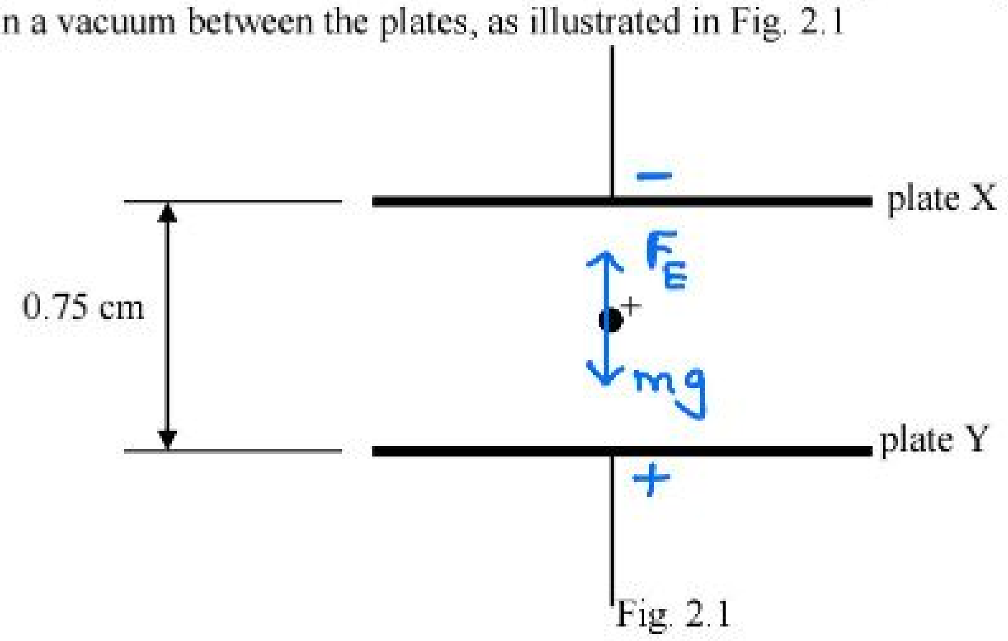


Fig. 2.1

The potential difference between the plates is adjusted until the particle remains stationary.

(a) State, with a reason, which plate, X or Y, is positively charged.

Plate Y because upward Electric force is balanced by downward weight. [2]

(b) The potential difference required for the particle to be stationary between the plates is found to be 630 V. Calculate

(i) the electric field strength between the plates,

$$E = \frac{\Delta V}{\Delta d} = \frac{630}{0.75 \times 10^{-2}}$$

Field strength = 8.4×10^{4} N C^{-1} [2]

(ii) the charge on the particle.

upward F_E = Downward W

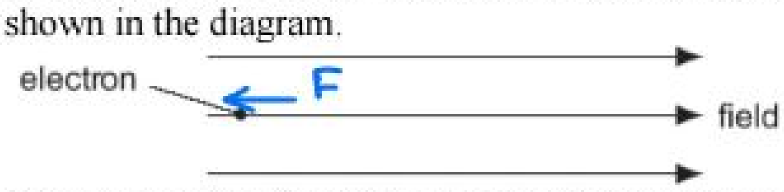
$$Eq = mg \Rightarrow q = \frac{mg}{E}$$

$$q = \frac{(9.6 \times 10^{-15})(9.81)}{8.4 \times 10^{4}}$$

Charge = ... C [3]

Multiple Choice Questions

1. An electron is situated in a uniform electric field, as shown in the diagram.

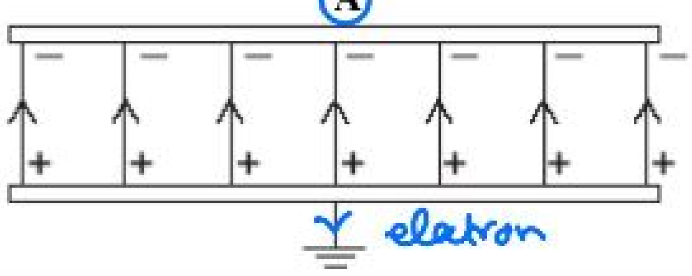


What is the direction of the electric force acting on the electron?

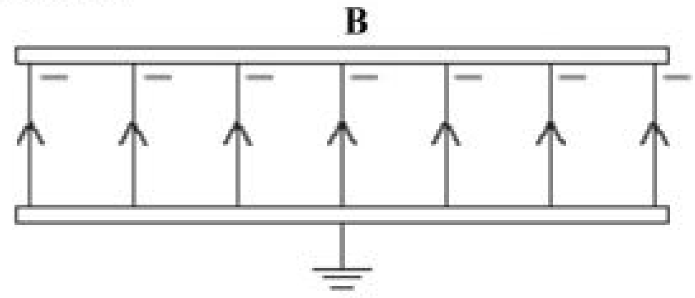
A downwards **B** to the left
C to the right **D** upwards

2. Two parallel, conducting plates with air between them are placed close to one another. The top plate is given a negative charge and the bottom one is earthed. Which diagram best represents the distribution of charges and the field in this situation?

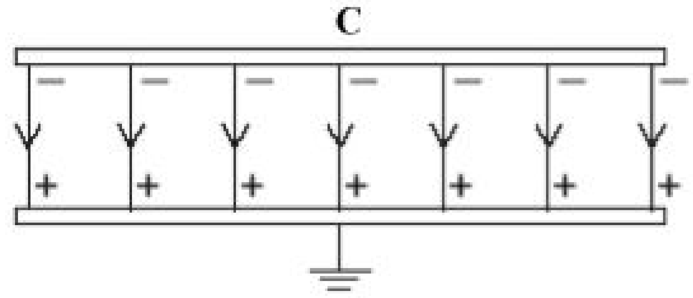
A



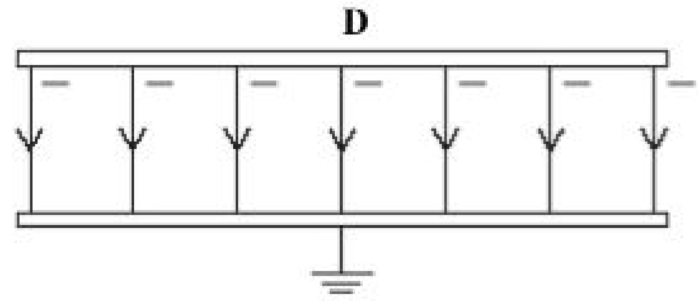
B



C



D



Akhtar Mahmood (0333-4281759)
M.Sc.(Physics), MCS, MBA-IT, B.Ed.
MIS, DCE, D AS/400e(IBM), OCP(PITB)
teacher_786@hotmail.com

3. An electron travelling horizontally in a vacuum enters the region between two horizontal metal plates, as shown in Fig. 3.1.

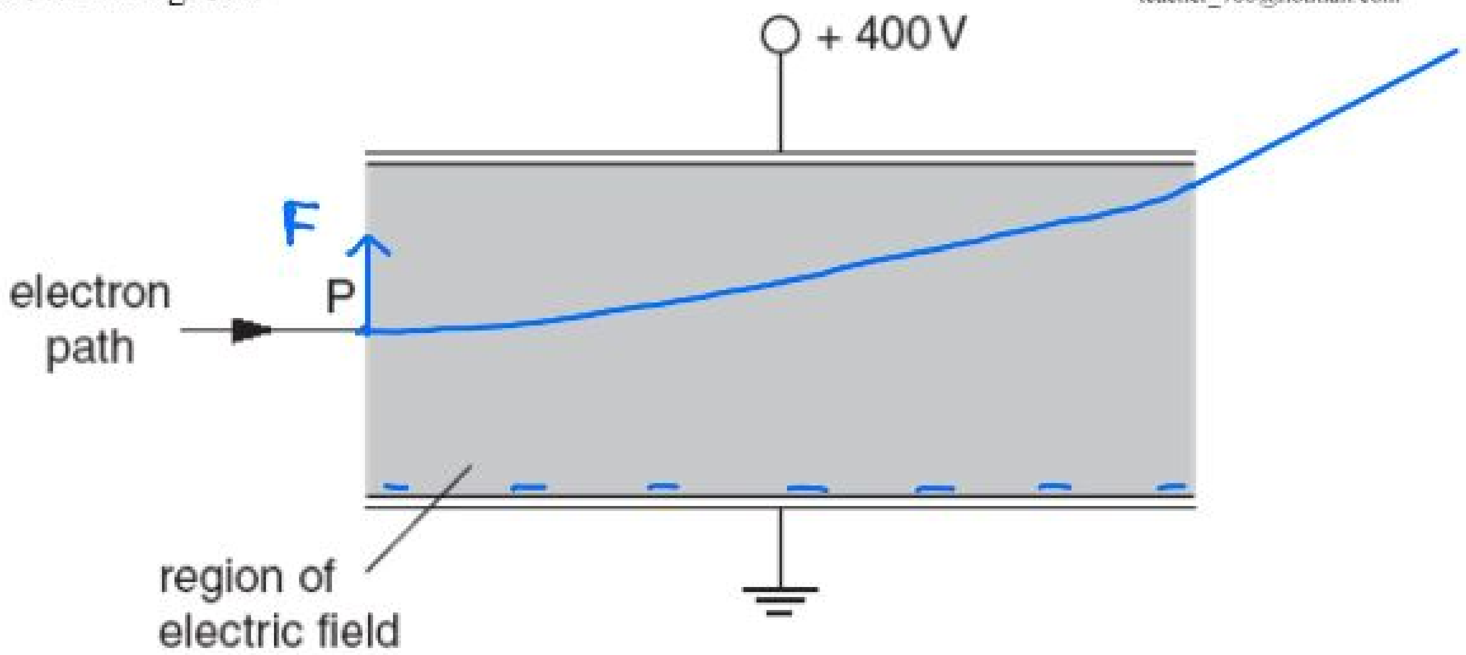


Fig. 3.1

The lower plate is earthed and the upper plate is at a potential of + 400V. The separation of the plates is 0.80 cm. The electric field between the plates may be assumed to be uniform and outside the plates to be zero.

(a) On Fig. 3.1,

(i) draw an arrow at P to show the direction of the force on the electron due to the electric field between the plates,

(ii) sketch the path of the electron as it passes between the plates and beyond them.

[3]

(b) Determine the electric field strength E between the plates.

$$E = \frac{\Delta V}{\Delta d} = \frac{400 - 0}{0.80 \times 10^{-2}} = 5.0 \times 10^{4}\ \text{N C}^{-1}$$

E = 5.0×10^{4} V m^{-1} [2]

(c) Calculate, for the electron between the plates, the magnitude of **(i)** the force on the electron,

$$F = Eq$$
$$= (5.0 \times 10^{4})(1.60 \times 10^{-19})$$
$$= 8.0 \times 10^{-15}\ \text{N}$$

force = ... N

(ii) its acceleration.

$$F = ma$$
$$8.0 \times 10^{-15} = (9.11 \times 10^{-31})a$$
$$a = 8.78 \times 10^{15}\ \text{m s}^{-2}$$

acceleration = ... ms^{-2}

[4]

(d) State and explain the effect, if any, of this electric field on the horizontal component of the motion of the electron.

Since Electric force acts vertically only and no force acts horizontal. So horizontal velocity remain constant (zero horizontal acceleration) [2]

Akhtar Mahmood (0333-4281759)
M.Sc.(Physics), MCS, MBA-IT, B.Ed.
MIS, DCE, D AS/400e(IBM), OCP(PITB)
teacher_786@hotmail.com

4. Two large flat metal plates **A** and **B** are placed 9.0 cm apart in a vacuum, as illustrated in Fig.4.1

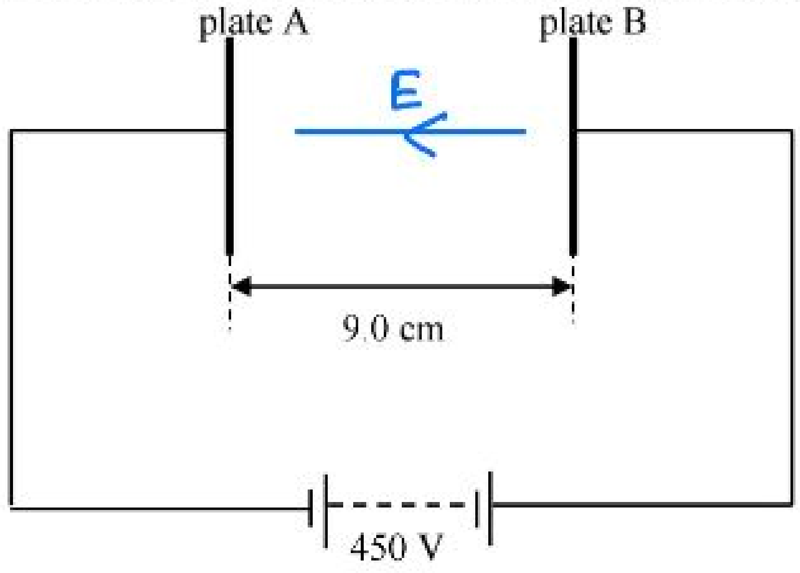


Fig. 4.1

A potential difference of 450 V is maintained between the plates by means of a battery.

(a) (i) On Fig. 4.1, draw an arrow to indicate the direction of the electric field between plates A and B.

(ii) Calculate the electric field strength between A and B.

$$E = \frac{\Delta V}{\Delta d} = \frac{450}{9.0\times10^{-2}}$$

Field strength = 5.0×10^{3} …………………………………… N C^{-1} [3]

(b) An electron is released from rest at the surface of plate A.

(i) Show that the change in electric potential energy in moving from plate A to plate B is 7.2 x 10^{-17} J.

$$V = \frac{W}{q} \Rightarrow V = \frac{E_p}{e}$$

$$E_p = Ve$$
$$= (450)(1.60\times10^{-19})$$
$$= 7.2\times10^{-17}\,\text{J}$$

(ii) Determine the speed of the electron on reaching plate B.

Gain in E_K = Loss of Electric E_p

$$\frac{1}{2}mv^2 = Ve$$

$$v = \sqrt{\frac{2Ve}{m}} \Rightarrow v = \sqrt{\frac{2(450)(1.60\times10^{-19})}{9.11\times10^{-31}}}$$

$$v = \quad ms^{-1}$$

Speed = …………………………………… ms^{-1} [4]

(c) On the axes of Fig. 4.2, sketch a graph to show the variation with distance d from plate A of the speed V of the electron. [1]

$$2as = v^2 - u^2$$
$$2\left(\frac{F}{m}\right)d = v^2 - (0)^2$$
$$2\left(\frac{Eq}{m}\right)d = v^2$$
$$(\text{constant})\,d = v^2$$
$$v^2 \propto d \Rightarrow v \propto \sqrt{d}$$

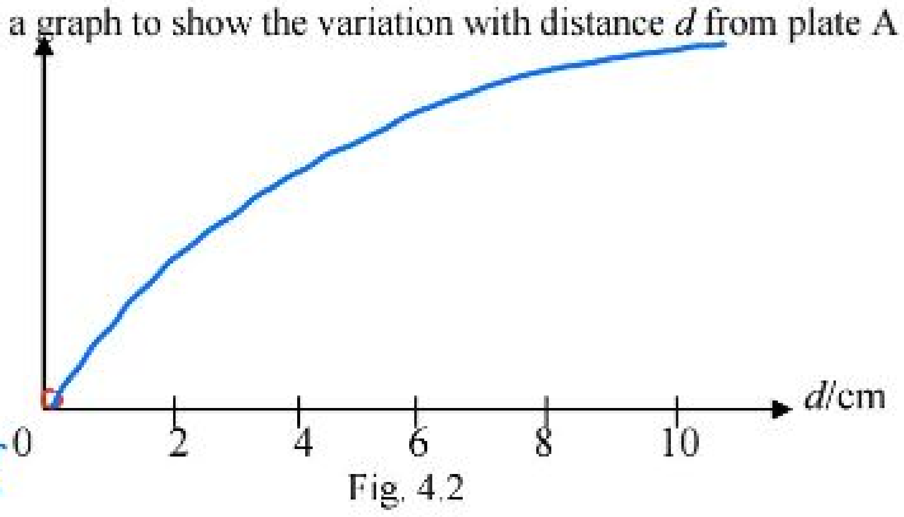


Fig. 4.2

d/cm	v/cms⁻¹
0	0
2	1.41
4	2
6	2.4
8	2.8
10	3.2