Electricity & Magnetism

Electric Fields

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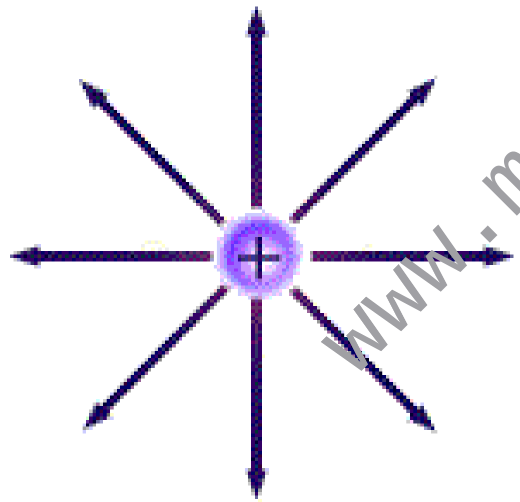
Electric Fields

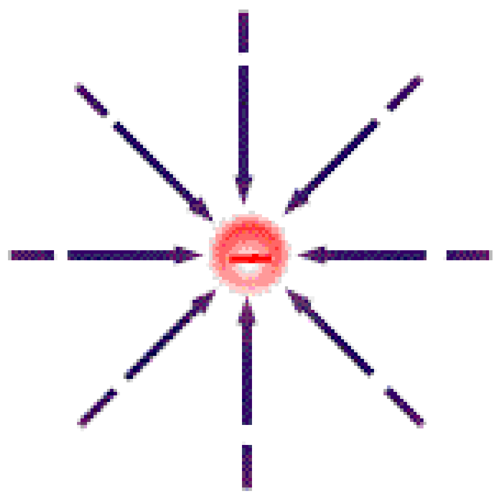
- Electric charges exert forces on each other when they are a distance apart. The word ‘Electric field’ is used to explain this action at a distance.
- An Electric field is defined as the region of space where a stationary charge experiences force.

The direction of Electric Fields

- The direction of electric field is defined as the direction in which a positive charge would move if it were free to do so. So the lines of force can be drawn with arrows that go from positive to negative.
- Electric field lines are also called force lines.
- The field lines are originated from the positive charge and they end up at the negative charge.



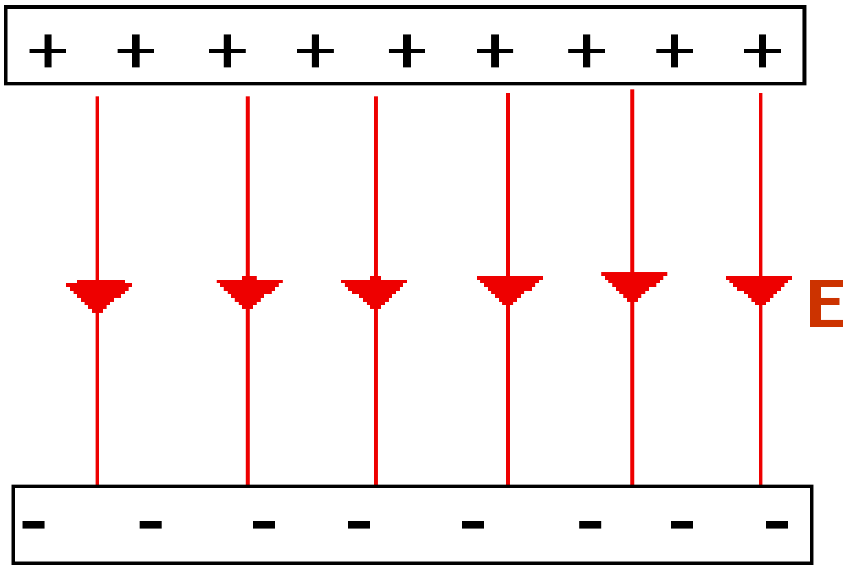
Positive Charge Electric Field
(animated demo)



Negative Charge Electric Field
(animated demo)

Remember, for any ELECTRIC FIELD.....

- The lines of force starts on a positive charge and end on a negative charge.
- The lines of force never touch or cross.
- The strength of the electric field is indicated by the closeness of the lines; means the closer they are, the stronger the field.



Electric Field Strength

- Electric field strength at a point is defined as the force per unit charge acting on a small positive charge placed at that point.
- If a force experienced by a positive charge +Q placed in the field is F, then the field strength, E is given by $E = \frac{F}{Q}$

Note : Remember, the symbol E is also used for 'energy'.

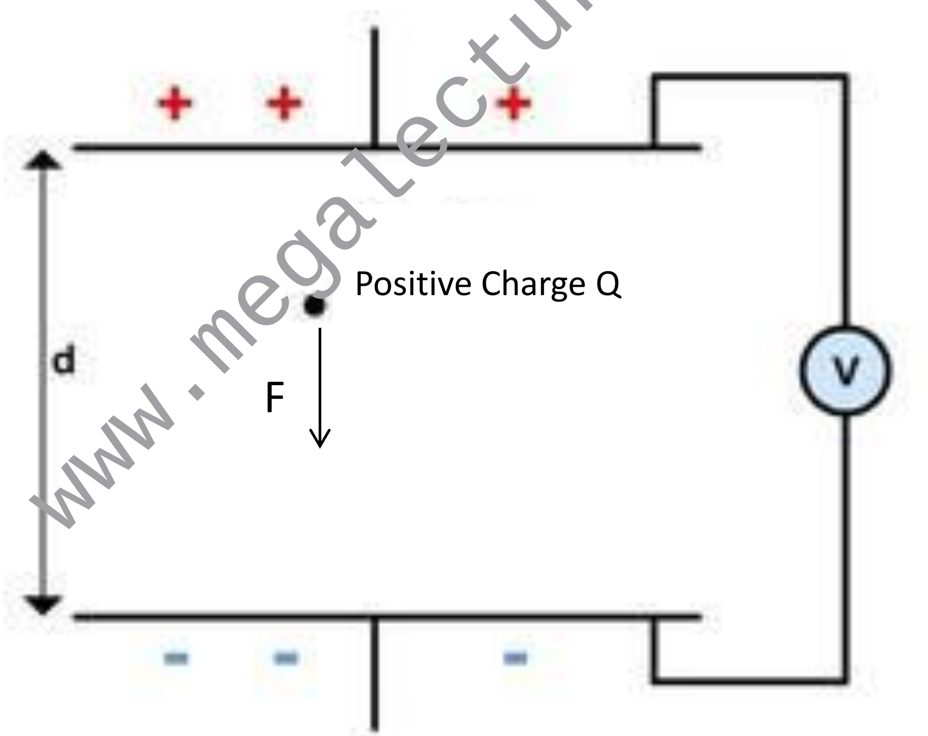
Unit of Electric Field Strength

- The unit of Electric field strength for the equation $E = \frac{F}{Q}$ is given by N C^{-1}

  where force is measured in Newtons and charge in Coulombs.

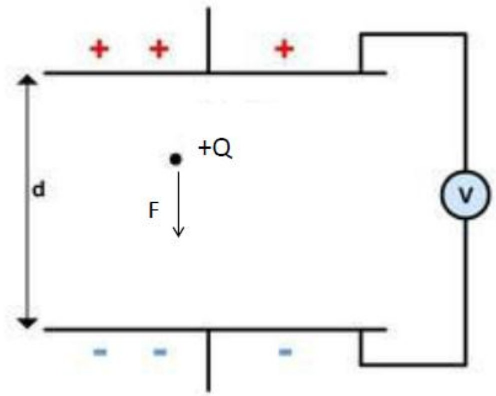
Note : Remember, later we shall see that there is another common SI unit for electric field strength, Vm^{-1} . However the 2 units are equivalent.

The field strength (E) of the uniform field between charged parallel plates in terms of potential difference (V) and separation (d)



The field strength of the uniform field between charged parallel plates in terms of potential difference and separation.

- The figure illustrates parallel plates at a distance d apart with a potential difference *V* between them.
- A charge +Q in the uniform field between the plates has a force *F* acting on it.



- To move the charge towards the positive plate would require work to be done on the charge.

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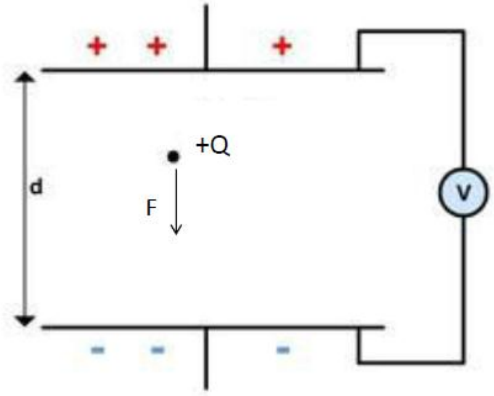
- Work done is given by the product of force and distance.
- To move the charge from one plate to other requires work W and is given by W = Fd, where F is force and d is the distance.



- Now lets see what is potential difference. (see next slide)

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So what is potential difference?

- If the electric field is ***NOT UNIFORM***, it is not so simple to calculate the energy change due to moving a charge in the field.

- *It is therefore useful to define a quantity which describes the work done in moving unit charge from one point in the field to another point*. We call this quantity the ***POTENTIAL DIFFERENCE*** between the two points and is given by $V = \frac{W}{Q}$

- V is the symbol for potential difference, which has units of ***JOULES PER COULOMB, (JC^{-1})***. As this is an important quantity, it is given its own unit, the ***VOLT, (V)***.

- ***"One volt is the potential difference between two points in an electric field such that one joule of work is done in moving one coulomb of charge from one point to another."***

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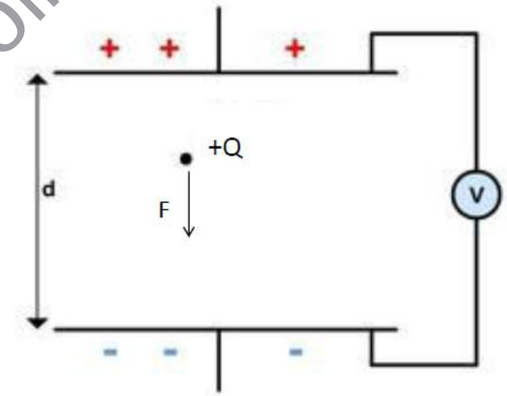
- By rearranging equation on potential difference, work done W = *V*Q
- Thus W = Fd = *V*Q
- $$\frac{F}{Q} = \frac{V}{d}$$



- But $\frac{F}{Q}$ is the force per unit charge and this is the definition of electric field strength.
- Thus, for a uniform field, the field strength E is given by E = $\frac{V}{d}$

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For parallel plates separated by a distance *d*, with a potential difference *ΔV*, the uniform electric field within the plates has strength:

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

We sometimes use an alternate unit for *E.*

$$E = \frac{Voltage}{\text{distance}}$$

$$= \frac{Volts}{metre}$$

$$= Vm^{-1}$$

Calculate the forces on charges in uniform electric fields.

$$\frac{F}{Q} = \frac{V}{d}$$

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

Sample problem 1 : Calculate E

Two parallel plates separated by **0.1m** have a potential difference **ΔV = 100V**. What is the Electric Field strength between the plates?

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

$$= \frac{100V}{0.1m}$$

$$= 1000Vm^{-1}$$

Sample problem 2 : Calculate E and F

- Two metal plates 5.0cm apart have a potential difference of 1000 V between them. Calculate :

(a) The strength of the electric field between plates.

(b) The force on a charge of 5.0 nC between the plates.

Solution :

(a) E = $\frac{V}{d}$, E = $\frac{1000}{0.05}$ = $\underline{2.0 \times 10^4\ Vm^{-1}}$

(b) F = EQ, F = $2.0 \times 10^4 \times 5.0 \times 10^{-9}$ = $\underline{1.0 \times 10^{-4}\ N}$

The effect of a uniform electric field on the motion of charged particles

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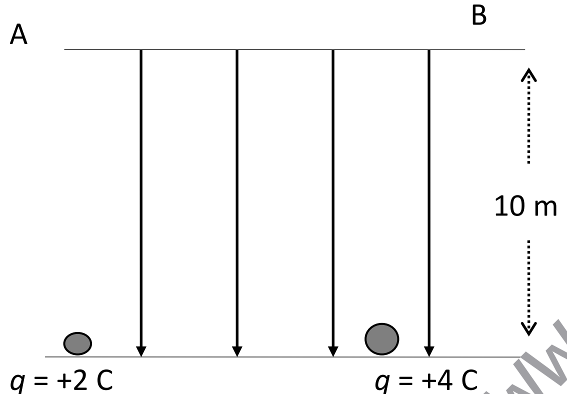
Energy Changes in Electric Fields

Consider the movement of a charge in a uniform electric field ;



$\boldsymbol{E}$ = 10 N C^{-1}

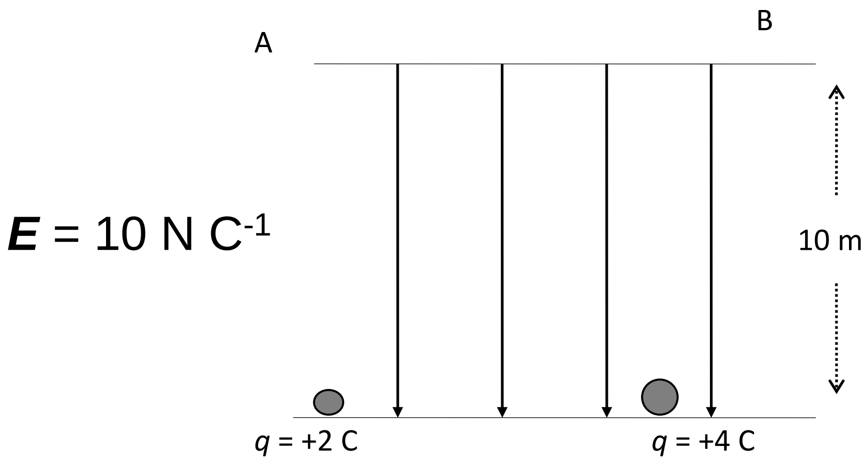
To lift a charge towards the top (positive) plate we exert an external force;
Therefore, Work Done by external Force is :

$$W = F_{ext} \times d$$
$$= EQ.d \qquad \text{(since } F = EQ\text{)}$$
$$= \frac{V}{d} \times Q \times d \qquad \left(\text{since } E = \frac{V}{d}\right)$$

$$W = QV$$

Sample problem 3 : Calculate the Work done

The work done on each charges are :



$$w = QEd$$
$$= 2 \times 10 \times 10$$
$$= 200J$$

$$w = QEd$$
$$= 4 \times 10 \times 10$$
$$= 400J$$

Sample problem 3 : Calculate V

We **define** the **Work done** (in moving charge from one position to another) **per unit charge** as the change in potential or **potential difference, V.**

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

Taking the data of W from previous sample problem, calculate V.

+2C Charge,

$$V = \frac{200J}{2C}$$

$$= 100JC^{-1}$$

+4C Charge,

$$V = \frac{400J}{4C}$$

$$= 100JC^{-1}$$

Electron Volt

Work done when a charge of one electron moves through a potential difference of 1 V is one electron volt (e.V).

The equivalent energy is:

Since W = QV

Q **= 1.6 x 10^{-19}C**, and **1 V = 1 J C^{-1}**

hence 1 eV = 1.6 x 10^{-19}C x 1 J C^{-1}

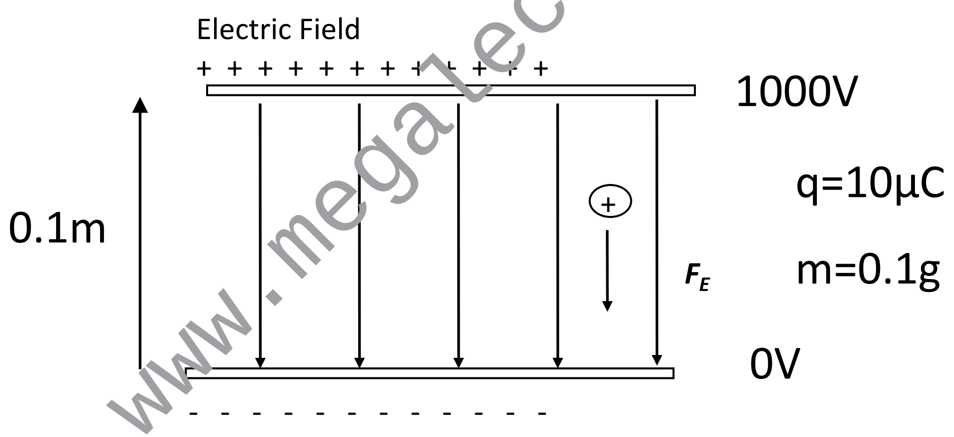
1 eV = 1.6 x 10^{-19} J

Motion in an Electric Field

Find the velocity using Equations of Motion

(with sample problem)

Consider a positive charge placed in a uniform electric field, as shown in the diagram below.



Find the velocity of the charge after it has travelled a distance of 5 cm. Use the following information:

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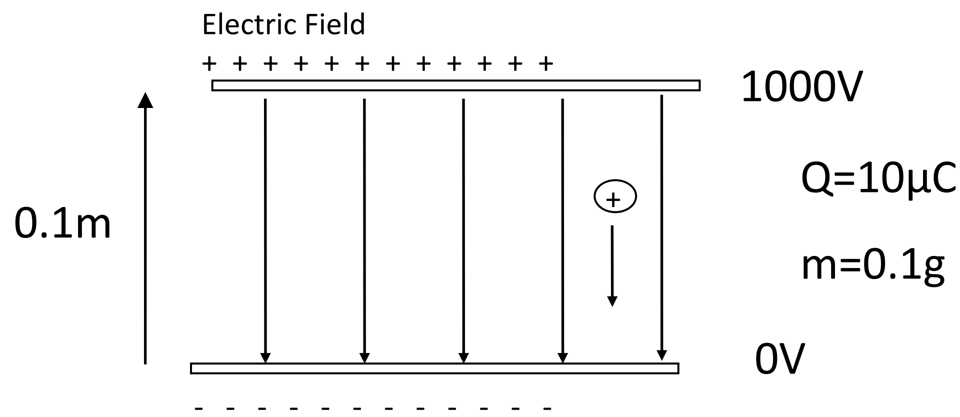
Motion in an Electric Field

Find the velocity using Equations of Motion

(with sample problem)

(continued from previous slide)



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

$$= \frac{1000}{0.1} = 1\times10^{4} Vm^{-1}$$

$$= 1\times10^{4} NC^{-1}$$

$$F = QE$$

$$= 10\times10^{-6}\times1\times10^{4}$$

$$= 10^{-1} N$$

$$a = \frac{F}{m}$$

$$= \frac{10^{-1}}{10^{-4}} = 10^{3} ms^{-2}$$

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Motion in an Electric Field

Find the velocity using Equations of Motion

(with sample problem)

(continued from previous slide)

Can use the equations of motion to determine the speed of particle after travelling for 5cm.

$$v_1 = 0ms^{-1} \quad \mathrm{d} = 0.05m \quad \mathrm{a} = 10^3 ms^{-2} \quad \mathrm{v}_2 = ?$$

$$\mathrm{v}_2^2 - v_1^2 = 2as$$

$$v_2^2 = 2as \quad (\mathrm{v}_1 = 0ms^{-1})$$

$$v_2 = \sqrt{2as}$$

$$v_2 = \sqrt{2 \times 10^3 \times 0.05}$$

$$v_2 = 10ms^{-1} \text{ towards the -'ve plate}$$

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Motion in an Electric Field

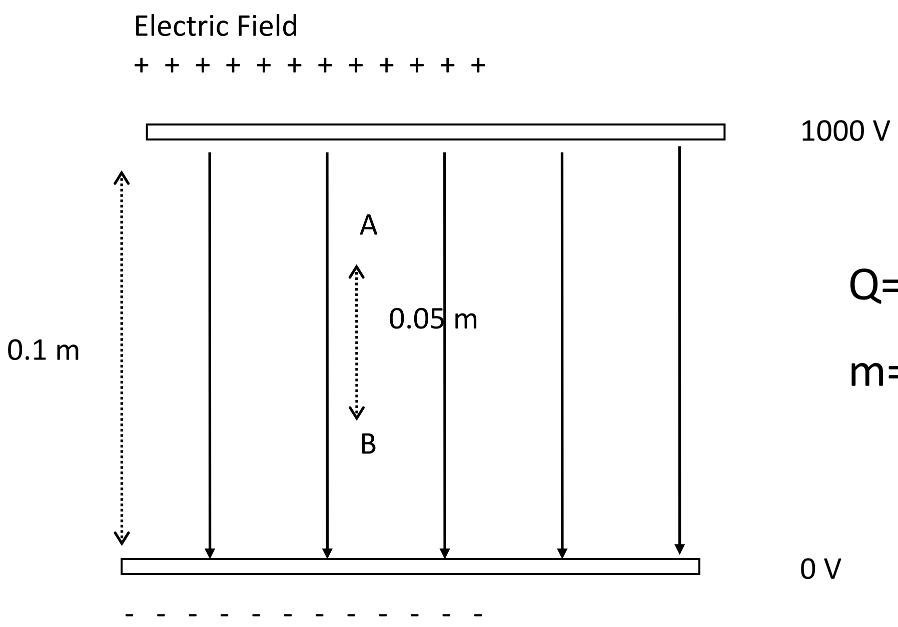
Find the velocity using Change in K.E

(with sample problem)

Can also determine the velocity by using the change in kinetic energy of the particle.

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

$$= 10000 Vm^{-1}$$



Q=10μC

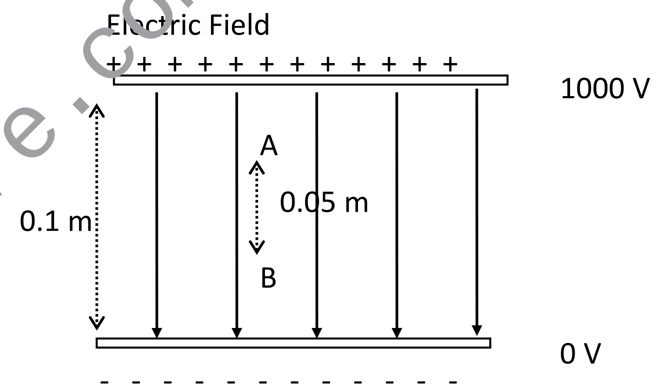
m=0.1g

Motion in an Electric Field

Find the velocity using Change in K.E

(with sample problem)

(Continued)



Q=10μC

m=0.1g

To find the potential difference between A and B, rearrange the equation,

$$E = \frac{\Delta V}{\Delta s}$$

$$\therefore \Delta V = E\Delta s$$

$$\therefore \Delta V = 10000Vm^{-1} \times 0.05m$$

$$\therefore \Delta V = 500V$$

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Motion in an Electric Field

Find the velocity using Change in K.E

(with sample problem)

(Continued)

Now calculate the kinetic energy at point B. If the charge is released at rest,

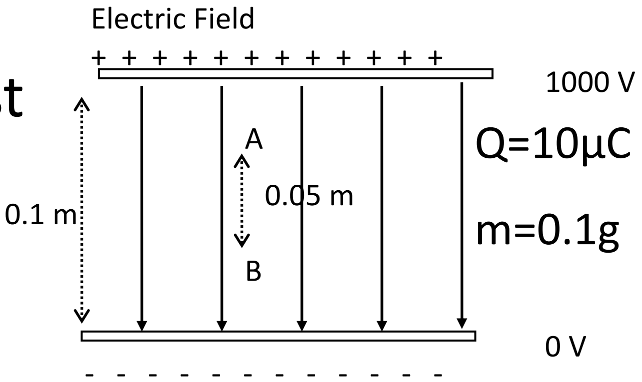
$K.E$ at B (Gain in $K.E$) = $P.E$ lost

$$\tfrac{1}{2} m v^2 = q \Delta V$$

$$\therefore v = \sqrt{\frac{2 q \Delta V}{m}}$$

$$= \sqrt{\frac{2 \times (10 \times 10^{-6}) \times 500}{10^{-4}}}$$

$$= 10 ms^{-1} \text{ towards the -'ve plate}$$



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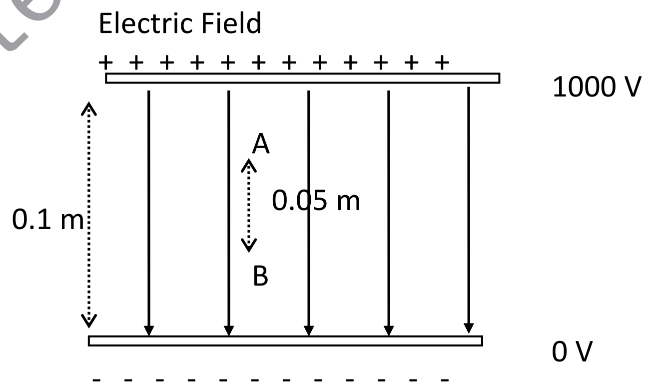
Motion in an Electric Field
Find the K.E from the work done
(with sample problem, data from previous slide)

The work done by the field on the charge can be calculated easily because it is equal to the gain in kinetic energy by the charge.

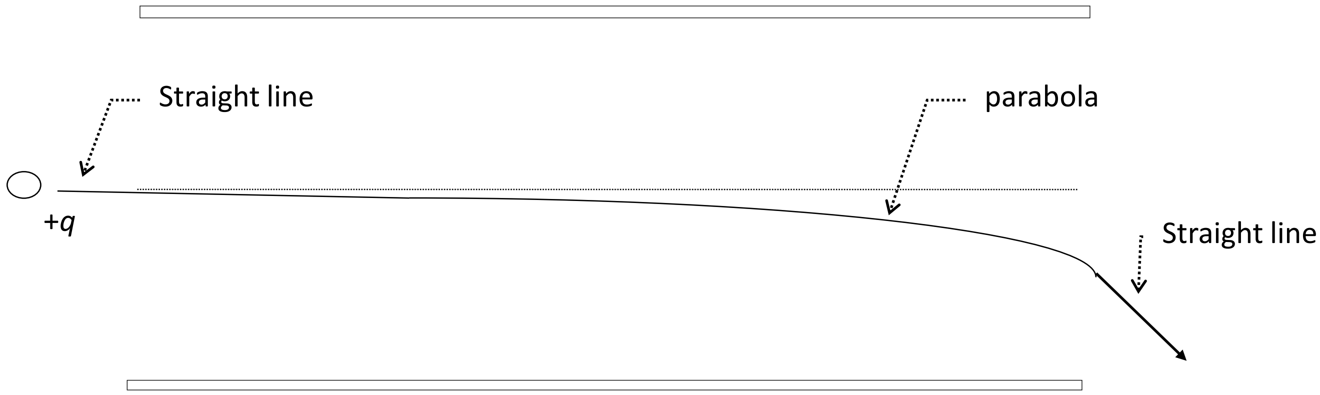
$$\Delta E_K = W = q\Delta V$$
$$= 10^{-5} \times 500$$
$$= 5\times10^{-3}$$
$$= 5mJ$$



Q=10μC

m=0.1g

For a charge that enters the Electric Field...



Horizontal Component of the velocity (H component)

$$v_h = v_{1h} = v_{2h} \text{ horizontal velocity is constant}$$

$$v_h = \frac{L}{\Delta t} \quad \text{so} \quad \Delta t = \frac{L}{v_h}$$

$$a = 0 \quad \text{as} \quad \Delta v = 0$$

For a charge that enters the Electric Field...

(continued from previous slide)

Vertical Component of the velocity (*v* component)

As it is initially travelling **horizontally**,
$v_{y1} = 0$ m/s
Where v_{y1} is initial vertical velocity and v_{y2} is final vertical velocity

$$\text{Now} \quad a_v = \frac{F}{m} = \frac{QE}{m}$$

$$\textit{And}, \quad v_{y2} = a\Delta t$$

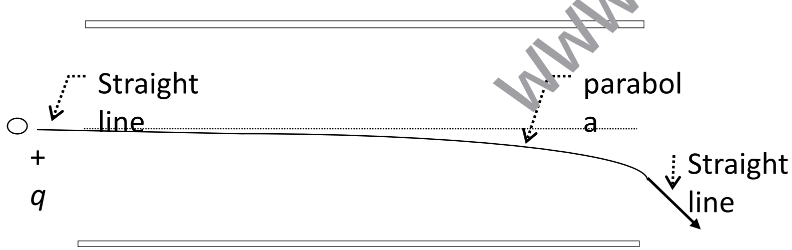
$$= \frac{QE}{m}\frac{L}{v_x}$$

$$\textit{So}, \quad \Delta s_v = \tfrac{1}{2} a_v \left(\frac{L}{v_x}\right)^2$$

$$\therefore \Delta s_v = \tfrac{1}{2} a_v \frac{L^2}{v_x^2}$$

v = u + at

S = ut + ½ at



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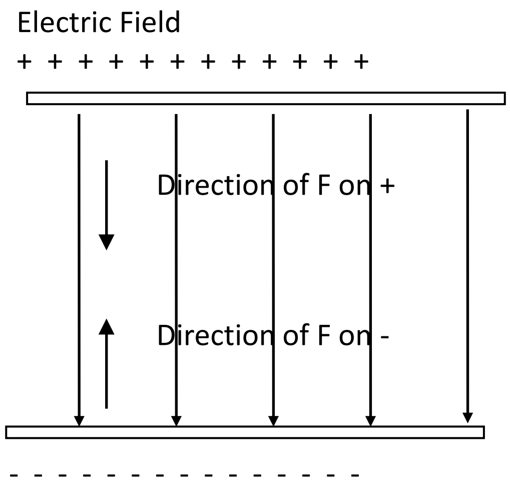
The direction of the force in an electric field



The direction of the force depends on the charge on the particle.

Assumptions

(just for your info only)

Assumptions

- ignore fringe effects (ie. assume that the field is completely uniform)

- ignore gravity (the acceleration due to gravity is insignificant compared with the acceleration caused by the electric field).

> For a charge that enters the field :

-Before entering electric field, the charge follows a **straight line path** (no net force)

-As soon as it enters the field, the charge begins to follow a **parabolic path** (constant force always in the same direction)

- As soon as it leaves the field, the charge follows a **straight line path** (no net force)