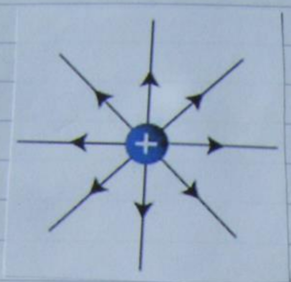
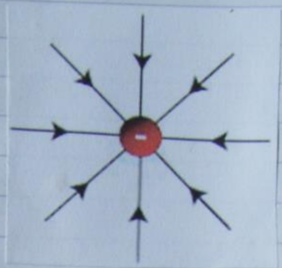
Electric Fields – B McMULLEN

There are two types of charge i.e positive and negative.



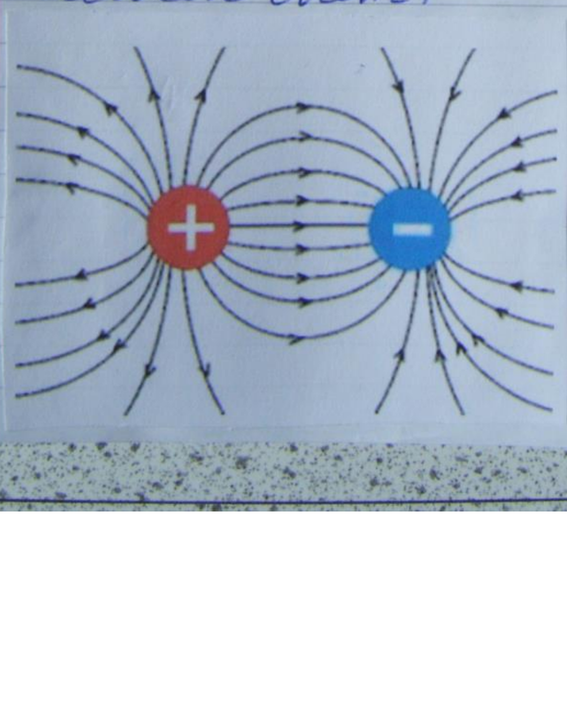


The electric field lines from the charges have their direction shown from the arrows.
(Out of positive and Into negative)

Forces between charges

- Unlike charges attract

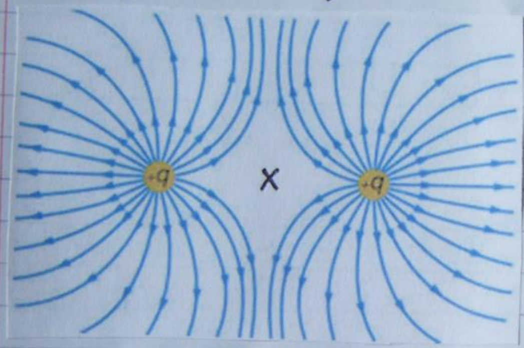
This means that if a positive and a negative charge come together there will be a force of attraction between them.



This shows the electric field pattern between two equal and opposite point charges.

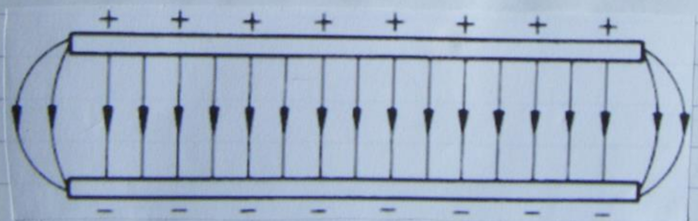
- Like charges repel

This means that if a positive charge is brought near another positive charge then there will be a force of repulsion between them. (This is the same when two negative charges are brought together!!)



This shows the electric field pattern between two positive point charges. (Electric field at point X=0).

Uniform electric Fields



- The electric field lines run from the +ve plate to the −ve plate
- The field lines are equally spaced in a uniform electric field.

What is meant by a uniform electric field?

If a charge is placed into a uniform electric field then the electric force acting on it will be the same at any point in the field.

** Definition of electric field strength

This is the force acting on unit positive charge in an electric field.

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

- E → Electric field strength (NC^{-1})
- F → Electric Force (N)
- Q → charge (C)

Equation for info only!!

** Definition of electric current

This is the number of coulombs of charge that pass a point per second.

From $Q = It \Rightarrow I = \frac{Q}{t}$

- I → Current (A)
- Q → Charge (C)
- t → time (s)

With $1A = 1Cs^{-1}$

ie 1 Ampere = 1 Coulomb per second.

** Definition of Voltage/potential difference

This is the electrical energy given to each coulomb of charge.

From $E_W = QV \Rightarrow$ $V = \frac{E_W}{Q}$

- E_W → Electrical work done (J)
- V → Voltage/potential difference (V)
- Q → Charge (C)

With $1\,V = 1\,JC^{-1}$

ie 1 Volt = 1 Joule per coulomb.

Ex 1

Q/ Calculate the electrical work done (E_W) in moving an electron through an electric field of potential difference 2.9kV.

Electron Data

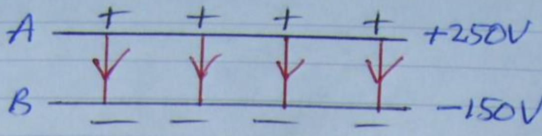
$M_e = 9.11 \times 10^{-31}\,kg$

$Q_e = (-)1.6 \times 10^{-19}\,C$

A/ $E_W = QV = 1.6 \times 10^{-19} \times 2.9 \times 10^{3}$

$E_W = 4.64 \times 10^{-16}\,J$

Ex2



Q: Calculate the electrical work done in moving a 400mC charge from A to B.

A: $E_W = ?$

$Q = 400mC = 400 \times 10^{-3} C$

$V = 250 - (-150) = 400V$

$E_W = QV = 400 \times 10^{-3} \times 400$

$\Rightarrow E_W = 160J$

Ex3

Q: Calculate the charge given out by a digital camera rechargeable battery if it is labelled 1800mAh. (milliampere hours)

A: $Q = ?$

$I = 1800mA = 1800 \times 10^{-3} A$

$t = 1h = 60 \times 60 = 3600s$.

$Q = It = 1800 \times 10^{-3} \times 3600 = 6480C$

Ex4 ('C' standard Question)

Q Calculate the speed that an electron hits a target with if it passes through a deflection system held at 3.1kV.

DATA

A $V = 3.1kV = 3.1\times10^{3}V$

$m_e = 9.11\times10^{-31}kg$

$Q_e = (-)1.6\times10^{-19}C$.

Energy conversion

$E_W \rightarrow E_K$.

- $E_W = QV = 1.6\times10^{-19} \times 3.1\times10^{3} = 4.96\times10^{-16}J$
- $E_W \rightarrow E_K \therefore E_K = 4.96\times10^{-16}J$
- $E_K = \frac{1}{2}mv^2$

$\Rightarrow 4.96\times10^{-16} = \frac{1}{2}\times9.11\times10^{-31}\times v^2$

$\Rightarrow 4.96\times10^{-16} = 4.556\times10^{-31}v^2$

$\Rightarrow v^2 = \frac{4.96\times10^{-16}}{4.556\times10^{-31}} = 1.089\times10^{15}$

$\Rightarrow v = 3.30\times10^{7}ms^{-1}$

(speed of electrons $\approx \times10^{7}ms^{-1}$).

Ex5

Q A proton initially at rest is accelerated through a potential difference of 4.2kV.
Calculate the speed at which the proton hits its target.

A

DATA

$m_p = 1.673 \times 10^{-27}$ kg

$Q_p = (+) 1.6 \times 10^{-19}$ C

$E_W \rightarrow E_K$

$E_W = QV = 1.6 \times 10^{-19} \times 4.2 \times 10^{3} = 6.72 \times 10^{-16}$ J

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

$\Rightarrow 6.72 \times 10^{-16} = \frac{1}{2} \times 1.673 \times 10^{-27} \times v^2$

$\Rightarrow 6.72 \times 10^{-16} = 8.365 \times 10^{-28} v^2$

$\Rightarrow v^2 = \dfrac{6.72 \times 10^{-16}}{8.365 \times 10^{-28}} = 8.033 \times 10^{11}$

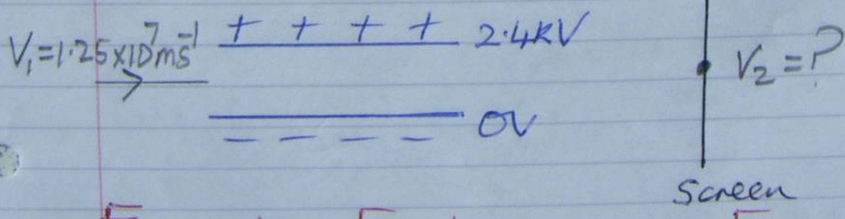
$\Rightarrow v = 8.96 \times 10^{5}$ ms^{-1}

(Speed of protons $\approx \times 10^{5}$ ms^{-1})

Ex6 ('A'/'B' Standard Question)

Q An electron travelling at 1.25×10^{7} ms^{-1} passes through a deflection system held at 2.4kV.

Calculate the speed at which the electron hits the target.



$E_{K_1} + E_W = E_{K_2}$

A $E_{K_1} + E_W = E_{K_2}$

- $E_{K_1} = \frac{1}{2}mv^2 = \frac{1}{2} \times 9.11\times10^{-31} \times (1.25\times10^7)^2$

$\Rightarrow E_{K_1} = 7.12\times10^{-17}J$

- $E_W = QV = 1.6\times10^{-19} \times 2.4\times10^3$

$\Rightarrow E_W = 3.84\times10^{-16}J$

- $E_{K_2} = E_{K_1} + E_W = 7.12\times10^{-17} + 3.84\times10^{-16}$

$\Rightarrow E_{K_2} = 4.55\times10^{-16}J$

- $E_{K_2} = \frac{1}{2}mv_2^2$

$\Rightarrow 4.55\times10^{-16} = \frac{1}{2} \times 9.11\times10^{-31} \times v_2^2$

$\Rightarrow 4.55\times10^{-16} = 4.56\times10^{-31} \times v_2^2$

$\Rightarrow v_2^2 = \dfrac{4.55\times10^{-16}}{4.56\times10^{-31}} = 9.98\times10^{14}$

$\Rightarrow v_2 = 3.16\times10^7 ms^{-1}$

(ie $\approx \times10^7 ms^{-1}$ for electrons)

Ex 7

Q A CAT scanner operates at 30KV and draws a current of 5mA.
Calculate or find:

a) The kinetic energy of the electrons as they hit the target.
b) The speed of the electrons as they hit the target.
c) The number of electrons that hit the target per second.
d) State the energy change when the electrons hit the target.

A a) DATA

$Q_e = (-)\,1{\cdot}6\times10^{-19}\,C$

$m_e = 9{\cdot}11\times10^{-31}\,Kg$

As the electrons are initially at rest then $E_W = E_K$.

$$E_W = QV = 1{\cdot}6\times10^{-19}\times 30\times10^{3} = 4{\cdot}8\times10^{-15}\,J$$

b) $E_K = E_W = 4{\cdot}8\times10^{-15}\,J$

$\therefore\ E_K = \frac{1}{2}mv^2$

$\Rightarrow 4{\cdot}8\times10^{-15} = \frac{1}{2}\times9{\cdot}11\times10^{-31}\times v^2$

$\Rightarrow 4{\cdot}8\times10^{-15} = 4{\cdot}556\times10^{-31}\times v^2$

$\Rightarrow v^2 = \dfrac{4{\cdot}8\times10^{-15}}{4{\cdot}556\times10^{-31}} = 1{\cdot}05\times10^{16}$

$\Rightarrow v = 1{\cdot}03\times10^{8}\,ms^{-1}$

c) $Q = ?$ This is to find the ~~total~~ charge of the electrons hitting the target.

$I = 5mA = 5 \times 10^{-3} A$

$t = 1s$

- $Q = It = 5 \times 10^{-3} \times 1 = \underline{5 \times 10^{-3} C}$
- Using ratios $1.6 \times 10^{-19} C \rightarrow 1$ electron

$\therefore 5 \times 10^{-3} C \rightarrow \frac{5 \times 10^{-3}}{1.6 \times 10^{-19}} = 3.125 \times 10^{16}$ electrons

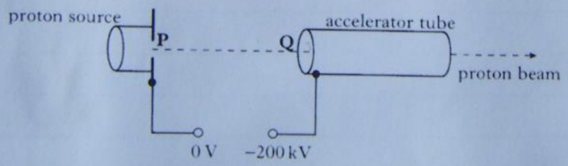
d) Energy change $E_K \rightarrow$ light energy.

ie Kinetic energy into light energy.

Ex8 (2006 PAPER Q24)

Q/

The diagram below shows the basic features of a proton accelerator. It is enclosed in an evacuated container.



Protons released from the proton source start from rest at **P**.
A potential difference of 200 kV is maintained between **P** and **Q**.

(*a*) What is meant by the term *potential difference of 200 kV*? 1

(*b*) Explain why protons released at **P** are accelerated towards **Q**. 1

(*c*) Calculate:

(i) the work done on a proton as it accelerates from **P** to **Q**; 2

(ii) the speed of a proton as it reaches **Q**. 2

(*d*) The distance between **P** and **Q** is now halved.

What effect, if any, does this change have on the speed of a proton as it reaches **Q**? Justify your answer. 2

A a) 200kV = 200kJ of energy transferred to each coulomb of charge.

b) Protons have a +ve charge and ∴ charged particles in a magnetic/electric field will experience a force.

c) I) $E_W = ?$ $\quad E_W = QV$

$Q = 1.6 \times 10^{-19} C \quad \Rightarrow E_W = 1.6 \times 10^{-19} \times 200 \times 10^{3}$

$V = 200 \times 10^{3} V \quad \Rightarrow E_W = 3.2 \times 10^{-14} J$

II) $E_K = E_W \Rightarrow 3.2 \times 10^{-14} = \frac{1}{2} \times 1.673 \times 10^{-27} \times v^2$

as $E_K = \frac{1}{2} mv \Rightarrow 3.2 \times 10^{-14} = 8.365 \times 10^{-28} \times v^2$

$\Rightarrow v^2 = \frac{3.2 \times 10^{-14}}{8.365 \times 10^{-28}} = 3.83 \times 10^{13}$

$\Rightarrow v = 6.19 \times 10^{6} ms^{-1}$

d) No effect.

The speed of the proton can only be varied by changing the potential difference V.

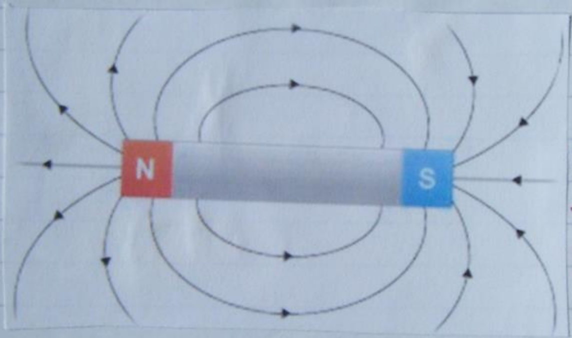
∴ Q and V are constant.

Magnetic Fields

A magnet has two poles ie a North Pole and a South Pole.

It is useful to compare the two poles of a magnet with the two types of charge. They behave the same way in terms of attractive and repulsive forces.

We have magnetic fields around a magnetic just like we have electric fields from point charges.



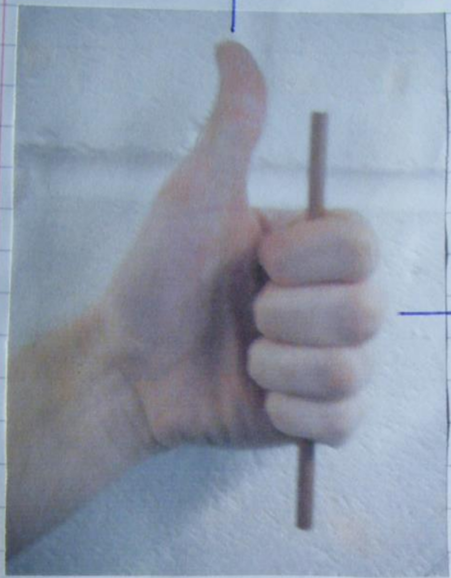
Very similar field pattern to a +ve and -ve charge in an electric field.

The magnetic field lines come out of the North Pole and then into the South Pole.

(** The magnetic field pattern produced between two North Poles or two South Poles would be a very similar field pattern to that of two positive charges or two negative charges in an electric field **.)

The left hand grip rule

Direction of Current through the conductor (electron flow)



Curl of the fingers → Direction of the magnetic field. around the conductor.

** In many textbooks they refer to the right hand grip rule. This is due to the use of conventional current instead of electron flow.

Current into the page

Current out of page

Think of an arrow where ⊙ is the point and ⊗ is the feather at the end.

* Current into the page *

- You can see the arrowhead ie ⊗ ie it is going away from you.
- The magnetic field lines are anti-clockwise around the conductor

* Current out of the page *

- You can see the arrowpoint ie ⊙ ie it is coming towards you.
- The magnetic field lines are clockwise around the conductor.

Fleming's Right hand Rule

F ALKIRK
F OOTBALL
C LUB

Thumb ⇒ Magnetic Force

First finger ⇒ magnetic field direction

Second finger ⇒ Current flow (electron flow).

This is often discussed as Fleming's left hand rule, but the current referred to is conventional current in this case.

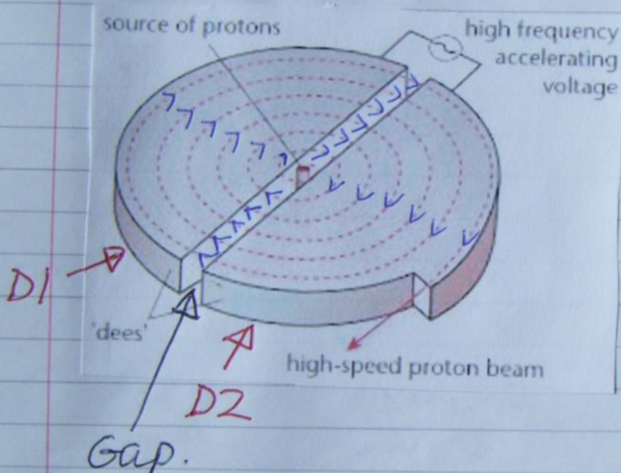
In Fleming's Right hand rule the force, field and current are all mutually perpendicular to each other.

CYCLOTRONS.

- Cyclotrons are used to accelerate protons.
- A cyclotron consists of an emitter and two 'dees'. These consist of two 'D' shaped boxes and are contained in a vacuum.
- The 'dees' are supplied with a high frequency ac supply.
- There is a large potential difference across the narrow gap between the 'dees'.
- Protons are emitted from the centre and will follow a curved path due to the magnetic field and will accelerate towards the first 'dee'.
- The proton will then accelerate when it reaches the gap between the 'dees'.

- This process continually repeats itself with the protons moving in a circular path of ever increasing radius.

- The protons then finally exit the accelerator as a high energy beam of protons that can be used in collisions.



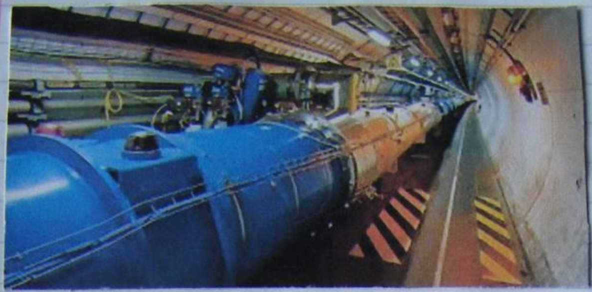
A cyclotron.

∧ - The arrow head shows the path of the proton beam.

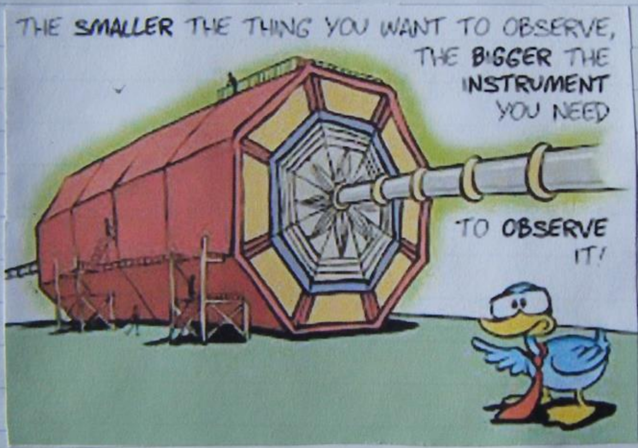
The cyclotron was originally developed as a particle accelerator for scientific development.

This has led on eventually to the creation of the LHC (Large Hadron Collider), the worlds highest energy particle accelerator.

LHC has a circumference of 27Km with the CERN built near Geneva in Switzerland. (part of it is in France).



A section of the 27km track of the LHC at CERN.



This is so true!!

Ex 9

A charged particle moves with a speed of $2 \cdot 0 \times 10^6 \, m\,s^{-1}$ in a circular orbit in a uniform magnetic field, shown in Figure 11.

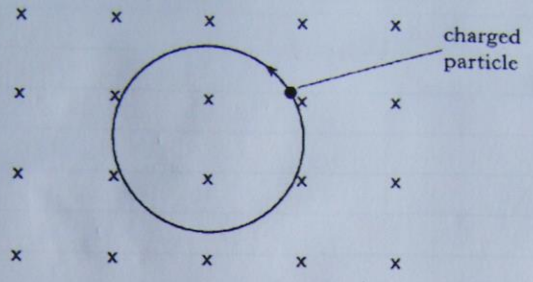


Figure 11

Q a) Is the charged particle in Figure 11 positive or negative.

b) Explain your answer in a) using the Right hand rule.

A a) Positive charge

b) Thumb → Force acting towards the centre of the circle to maintain the circular path

1st finger → Magnetic field into the paper ie ⊗

2nd finger → Current flow (electron) will be clockwise. (−ve)
∴ charge is +ve as it is moving anti-clockwise.

Ex10

A cyclotron is a particle accelerator which consists of two D-shaped hollow structures, called "dees", placed in a vacuum. Figure 10 shows an arrangement for a cyclotron.

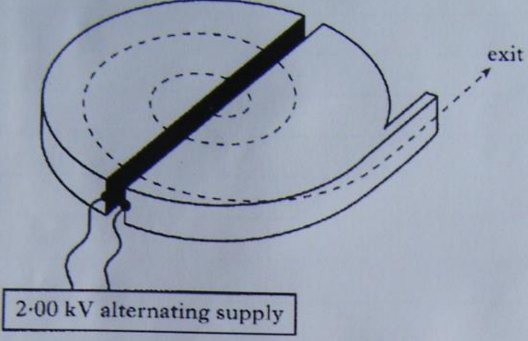


Figure 10

Figure 11 shows the cyclotron viewed from above.

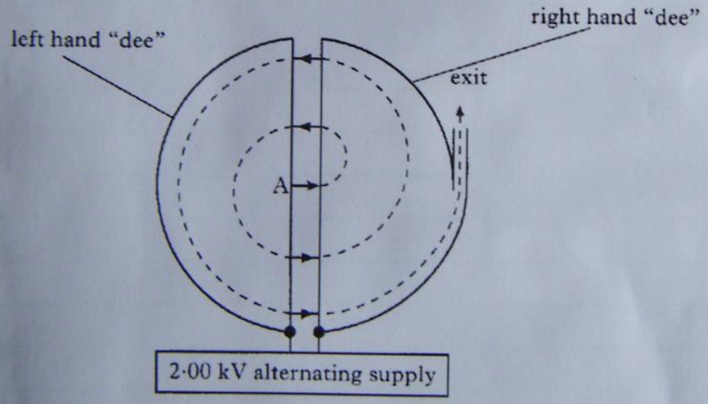


Figure 11

Q a) Protons are released from rest at point A and accelerated across the gap between the "dees" by a voltage of 2·00 kV.

Show that the speed of the protons as they **first** reach the right hand "dee" is $6{\cdot}19 \times 10^5\,\mathrm{m\,s^{-1}}$. 2

b) While the protons are inside the "dee", the polarity of the applied voltage is reversed so that the protons are again accelerated when they cross to the left hand "dee".

Calculate the speed of the protons as they **first** enter the left hand "dee". 2

A a) DATA

$m_p = 1.673 \times 10^{-27}$ kg

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

$V = 2.00$ kV

E_W on the proton = Gain in E_K of proton

$\Rightarrow \quad E_W = E_K$

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

$\Rightarrow \quad 1.6 \times 10^{-19} \times 2.00 \times 10^{3} = \frac{1}{2} \times 1.673 \times 10^{-27} \times v^2$

$\Rightarrow \quad 3.2 \times 10^{-16} = 8.365 \times 10^{-28} v^2$

$\Rightarrow \quad v^2 = \dfrac{3.2 \times 10^{-16}}{8.365 \times 10^{-28}} = 3.825 \times 10^{11}$

$\Rightarrow \quad v = 6.19 \times 10^{5}\ ms^{-1}$

b). $E_{K_2} = E_{K_1} + E_W$

$\Rightarrow \frac{1}{2}mv_2^2 = \frac{1}{2}mv_1^2 + QV$

$\Rightarrow \frac{1}{2} \times 1.673 \times 10^{-27} \times v_2^2 = 3.2 \times 10^{-16} + 3.2 \times 10^{-16}$

$\Rightarrow \quad 8.365 \times 10^{-28} v_2^2 = 6.4 \times 10^{-16}$

$\Rightarrow \quad v_2^2 = \dfrac{6.4 \times 10^{-16}}{8.365 \times 10^{-28}} = 7.65 \times 10^{11}$

$\Rightarrow \quad v_2 = 8.75 \times 10^{5}\ ms^{-1}$