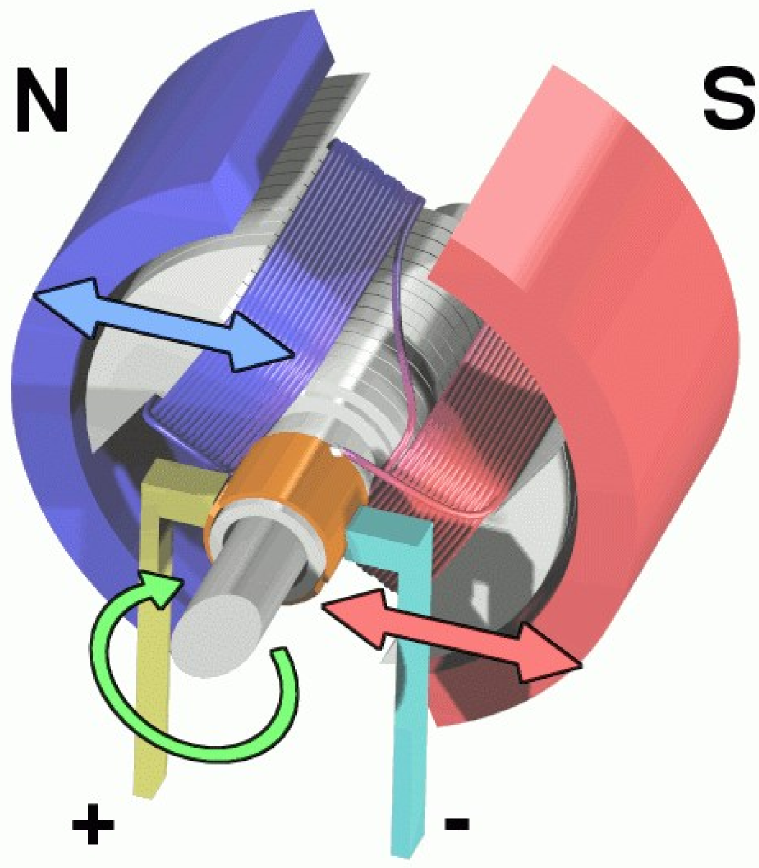


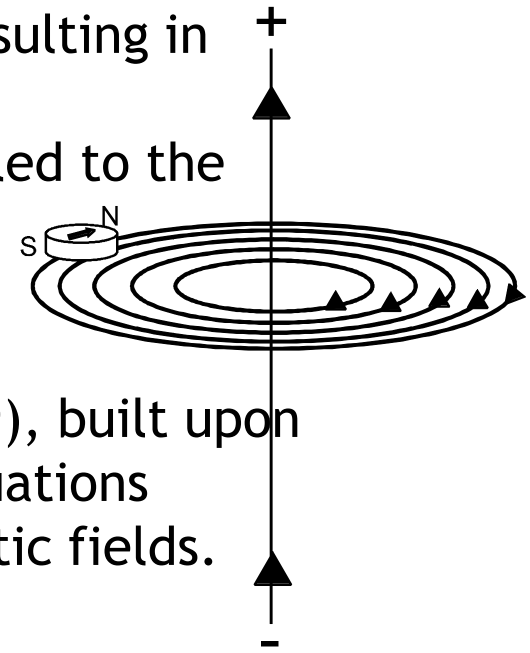
CHARGED PARTICLES IN FIELDS

HIGHER PHYSICS

CHARGED PARTICLES IN MAGNETIC FIELDS

The interaction between electricity and magnetism, resulting in movement had MASSIVE impact on everyday life.

Michael Faraday work electromagnetic rotation (1821) led to the electric motor.



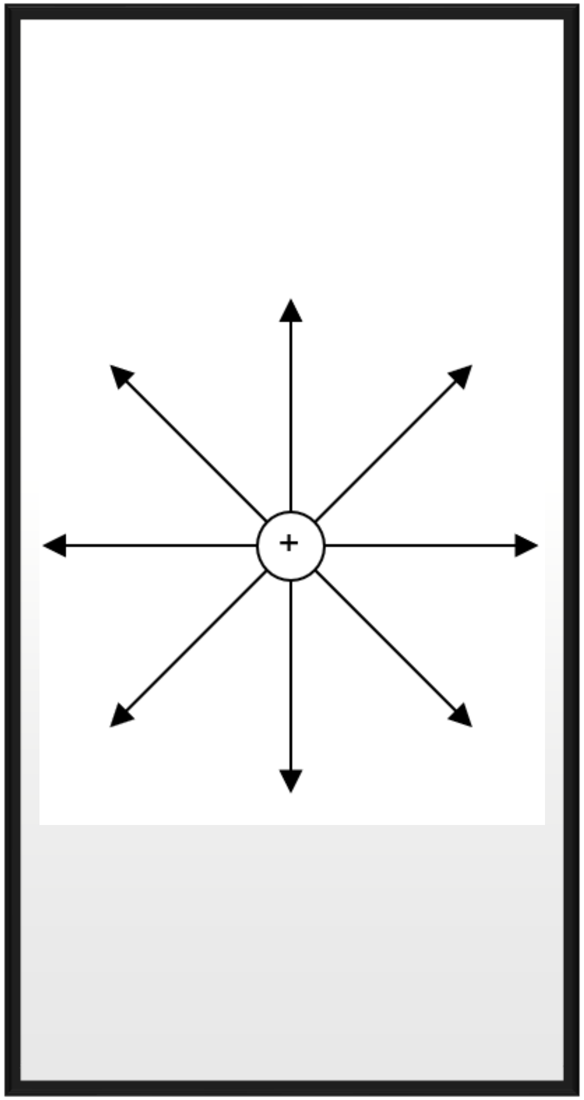
The Scottish physicist, James Clark Maxwell (1831–1879), built upon the work of Faraday and wrote down mathematical equations describing the interaction between electric and magnetic fields.

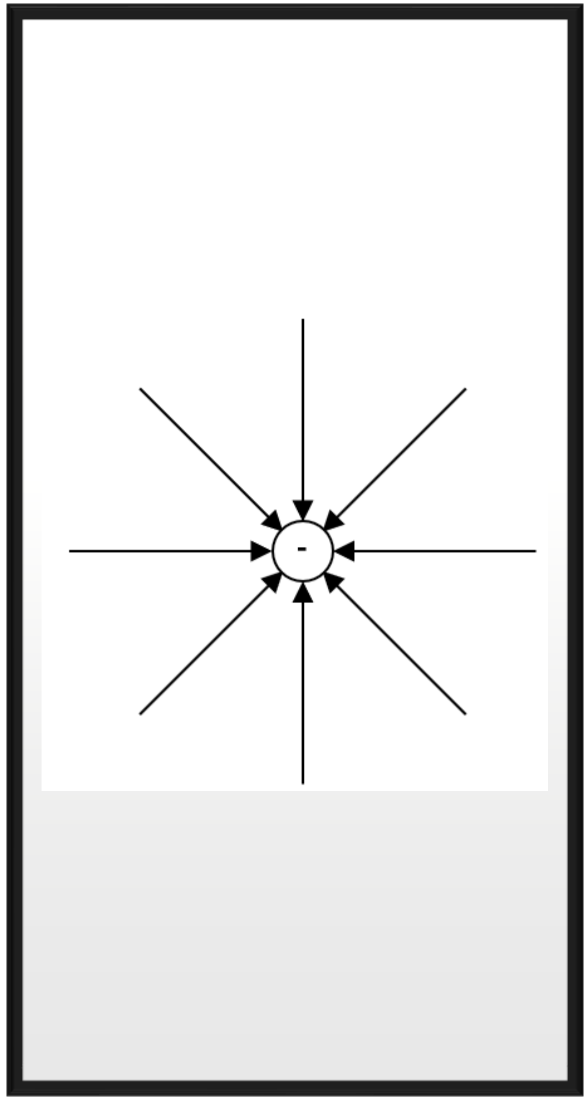
The computing revolution of the 20th century could not have happened without an understanding of electromagnetism.

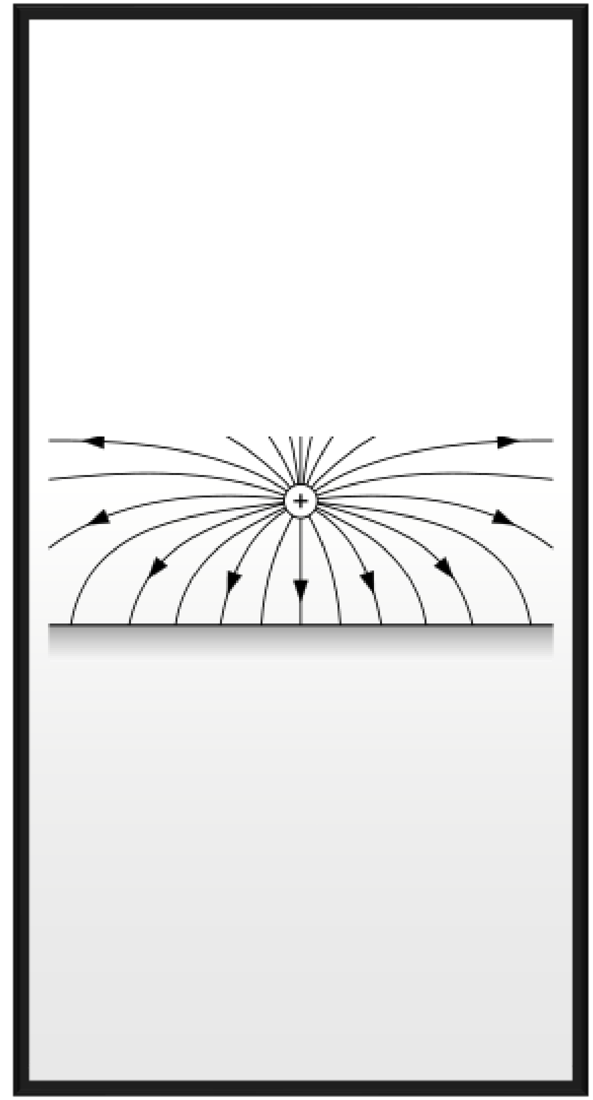
ELECTRIC FIELDS

In Physics, a field means a region where an object experiences a force.

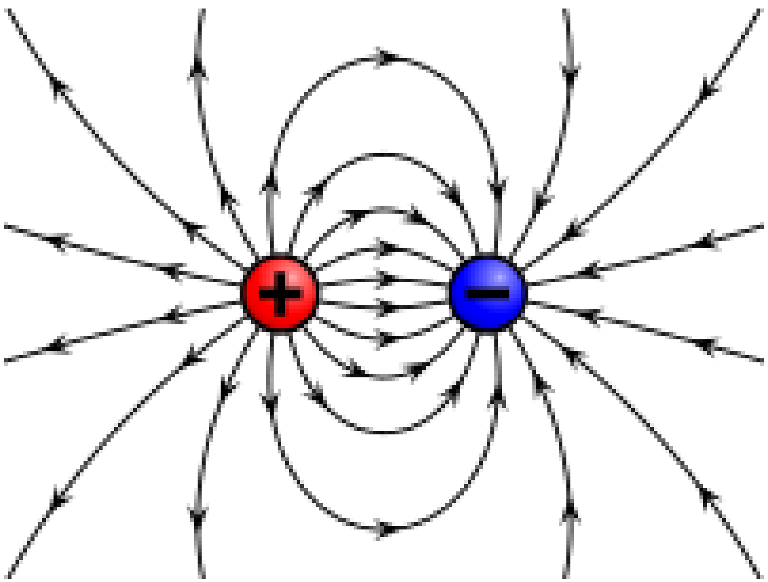
An ELECTRIC FIELD is a region where a CHARGE experiences a FORCE.

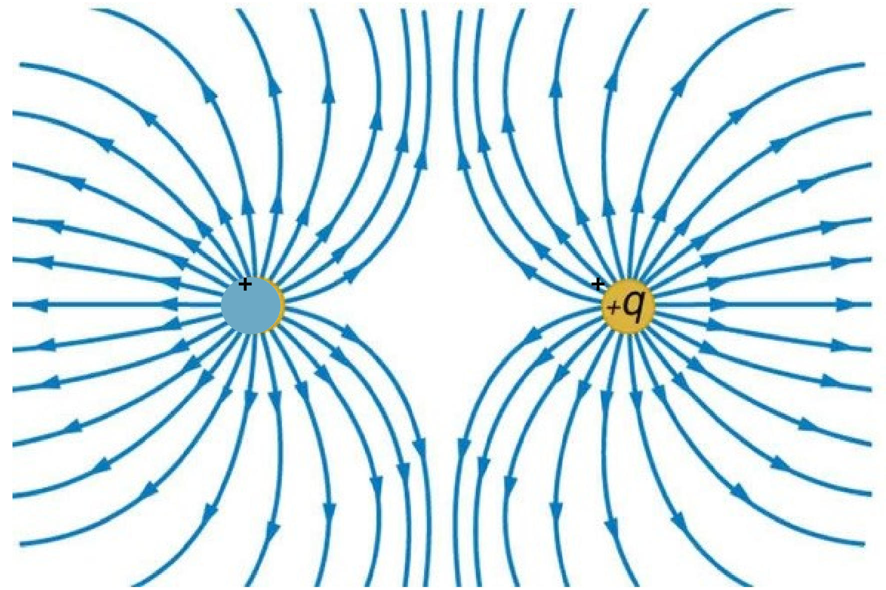




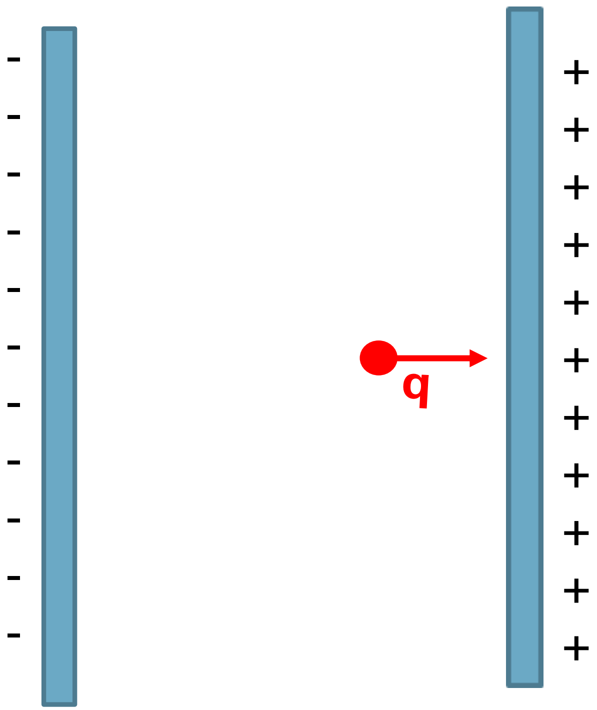


OPPOSITES & SIMILAR CHARGES





CHARGES IN ELECTRIC FIELDS



Work is done in moving the charge, q across the potential difference, V

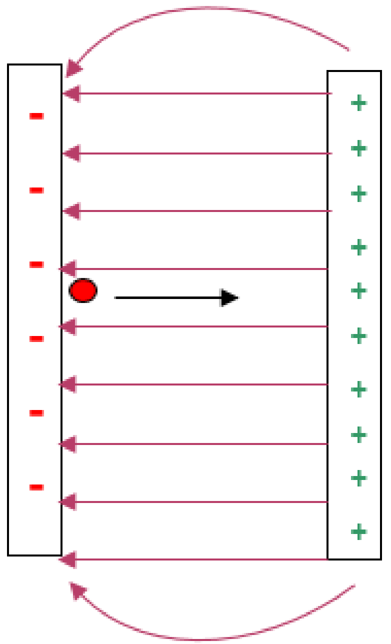
$$E_w = QV$$

This is converted to kinetic energy

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

These can be equated

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



The amount of work done is given by:-

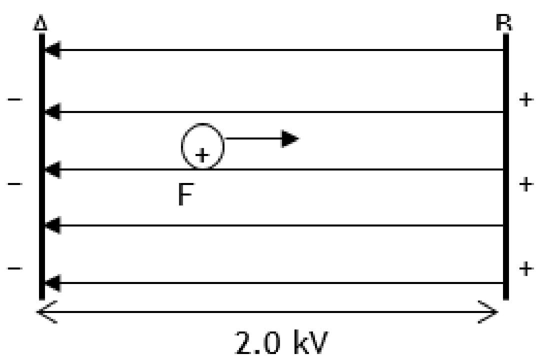
$$\text{work done} = \underset{\text{between plates}}{\text{potential difference}} \times \underset{\text{being moved}}{\text{charge}}$$

If positively charge Q is moved from the negative to the positive plate work has to be done against the field.

$$\text{work done} = p.d \times Q$$

As the field is uniform there is a constant force F on Q. The work done depends on the distance moved.

$$\text{work done} = \text{force} \times \text{distance}$$
$$E_W = Fd$$
$$but$$
$$E_W = QV$$
also the work done can be converted to E_k
$$QV = Fd = \Delta E_k$$
$$QV = \tfrac{1}{2}mv^2$$



Example: A positive charge of 3.0 μC is moved from A to B. The potential difference between A and B is 2.0 kV.

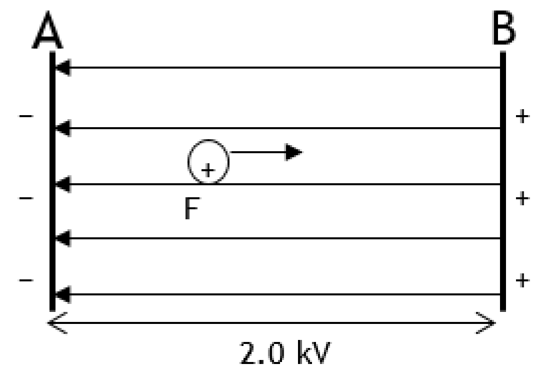
Example: A positive charge of 3.0 μC is moved from A to B. The p
and B is 2.0 kV.

(a) Calculate the electric potential energy gained by the charge–fi

(b) The charge is released. Describe the motion of the charge.

(c) Determine the kinetic energy when the charge is at point A.

(d) The mass of the charge is 5.0 μg. Calculate the speed of the



Solution:

(a) $Q = 3.0\ \mu C = 3.0 \times 10^{-6}$ C

$V = 2.0$ kV $= 2.0 \times 10^{3}$ V

$E_W = ?$

$E_W = QV$

$E_W = 3.0 \times 10^{-6} \times 2.0 \times 10^{3}$

$E_W = 6.0 \times 10^{-3}$ J

(b) The electric field is uniform so the charge experiences a constant unbalanced force. The charge accelerates uniformly towards the negative plate A.

(c) By conservation of energy,

$E_K = E_W = 6.0 \times 10^{-3}$ J

(d) $m = 5.0\ \mu g = 5.0 \times 10^{-9}$ kg

$E_K = 6.0 \times 10^{-3}$ J

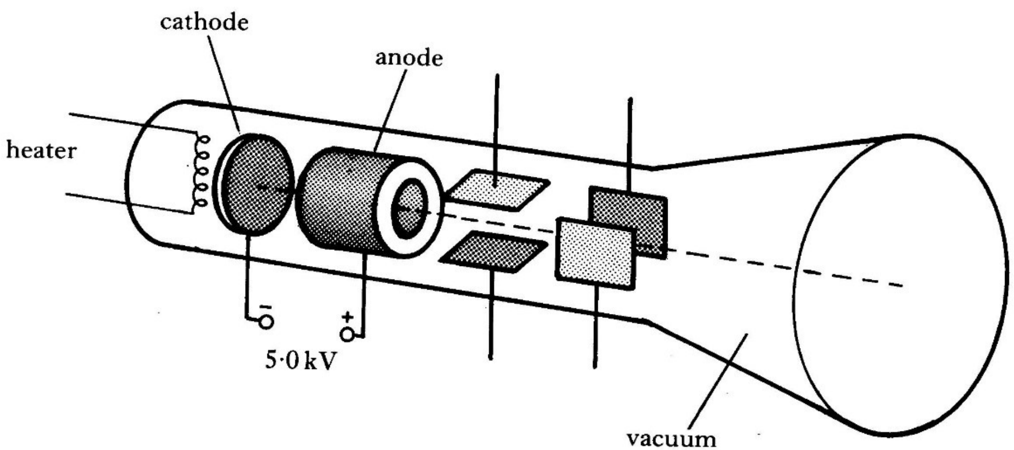
$v = ?$

$E_K = ½mv^2$ $6.0 \times 10^{-3} = 0.5 \times 5.0 \times 10^{-9} \times v^2$

$$v = \sqrt{\frac{2\times6.0\times10^{-3}}{5.0\times10^{-9}}} = 1.5\times10^{3}\,\text{m/s}$$

CATHODE RAY TUBES

https://www.youtube.com/watch?v=zj91VO7WJgU



The cathode ray tube (CRT) was invented in the 1800s but formed the basis of the majority of the world's new television technology until the end of the twentieth century. The cathode ray tube continues to be the basis for some scientific equipment such as the oscilloscope and radar systems. In the CRT an "electron gun" fires electrons at a screen.

Electrons, excited by heat energy from the filament, are emitted by the cathode and are accelerated forwards through a large potential difference towards the anode. The electrons pass through the cylindrical anode and a beam is formed. The grid is negative with respect to the cathode and some of the electrons are repelled back towards the cathode. It is made more negative by moving the variable resistor control towards A, more electrons will be repelled and so the beam becomes less intense and the spot dimmer.

- Potential differences applied to pairs of parallel plates are used to deflect the electron beam to different points on the screen. For the spot to be deflected to point T then plate Y_B must be more positive than plate Y_A and plate X_B must be more positive than plate X_A.

We can use this to calculate the speed of an electron within the electron gun as shown in the following example.

Example: An electron is accelerated from rest through a potential difference of 200 V. Calculate:

(a) the kinetic energy of the electron;

(b) the final speed of the electron.

(Note: in an exam, the mass and charge of the electron can be found on the data sheet.)

SOLUTION

(a) $Q = 1.60 \times 10^{-19}$ C

$V = 200$ V

$E_K = ?$

$E_K = E_W$ by the electric field

$E_K = QV$

$E_K = 1.60 \times 10^{-19} \times 200$

$E_K = 3.20 \times 10^{-17}$ J

(b) $m = 9.11 \times 10^{-31}$ kg

$E_K = 3.20 \times 10^{-17}$ J

$v = ?$

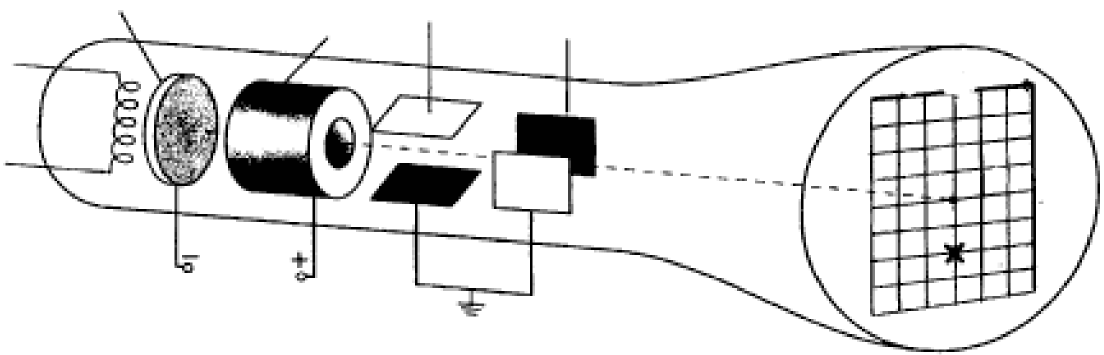
$E_K = ½mv^2$

$3.20 \times 10^{-17} = 0.5 \times 9.11 \times 10^{-31} \times V^2$

$V^2 = 7.025 \times 10^{13}$

$V = 8.38 \times 10^6$ m s^{-1}

EXAMPLE 2 ELECTRONS RELEASED FROM THE HOT CATHODE ARE ACCELERATED BY A P.D. OF 5.0 KV BETWEEN THE CATHODE AND ANODE.



(a)i) Assuming that an electron starts from rest at the cathode, calculate its speed just before it reaches the anode. (You may have to refer to the Science Data Booklet.)

ii) What is the effect on the speed of the electron just before it reaches the anode if the p.d. between the cathode and anode is halved? Show your reasoning.

(b) If the electron beam current is 15mA, how many electrons leave the cathode each second? (You may have to refer to the Science Data Booklet.)

SOLUTION

Solution:

(a) (i)

$$E_w = qV$$
$$E_w = 1.6\times10^{-19}\times5000$$
$$E_w = 8\times10^{-16}\,J$$

Work done against the field = kinetic Energy gained

$$E_K = \tfrac{1}{2}mv^2$$
$$8\times10^{-16} = \tfrac{1}{2}\times9.11\times10^{-31}\times v^2$$
$$\frac{8\times10^{-16}\times2}{9.11\times10^{-31}} = v^2$$
$$v = \sqrt{\frac{8\times10^{-16}\times2}{9.11\times10^{-31}}}$$
$$v = 4.2\times10^{7}\,ms^{-1}$$

(a) (ii) If the pd is halved the E_k will halve, however E_k is directly proportional to v^2 so v^2 will also halve this means that v will be a quarter of the original value. Completing a calculation is good exam practice if you've time!

(b)

$$I = 15mA$$
$$Q = It$$
$$Q = 15\times10^{-3}\times1$$
$$Q = 15\times10^{-3}\,C$$

$$No. = \frac{Q_T}{Q_e} = \frac{15\times10^{-3}}{1.6\times10^{-19}} = 9.4\times10^{16}$$

EXAMPLE 3

- 3. The electrons which are emitted from the cathode start from rest and reach the anode with a speed of 4.2×10^7 m s^{-1}
- a) i) Calculate the kinetic energy in joules of each electron just before it reaches the anode.
- ii) Calculate the p.d. between the anode and the cathode.
-
- b) Describe how the spot at the centre of the screen produced by the electrons can be moved to position X.
- Your answer must make reference to the relative sizes and polarity (signs) of the voltages applied to plates P and Q.

SOLUTION

(a)

(i)

$$E_K = \frac{1}{2} mv^2$$
$$E_K = \frac{1}{2} \times 9.11 \times 10^{-31} \times (4.2 \times 10^7)^2$$
$$E_K = 8 \times 10^{-16} J$$

(ii)

Work done against the field = kinetic Energy gained

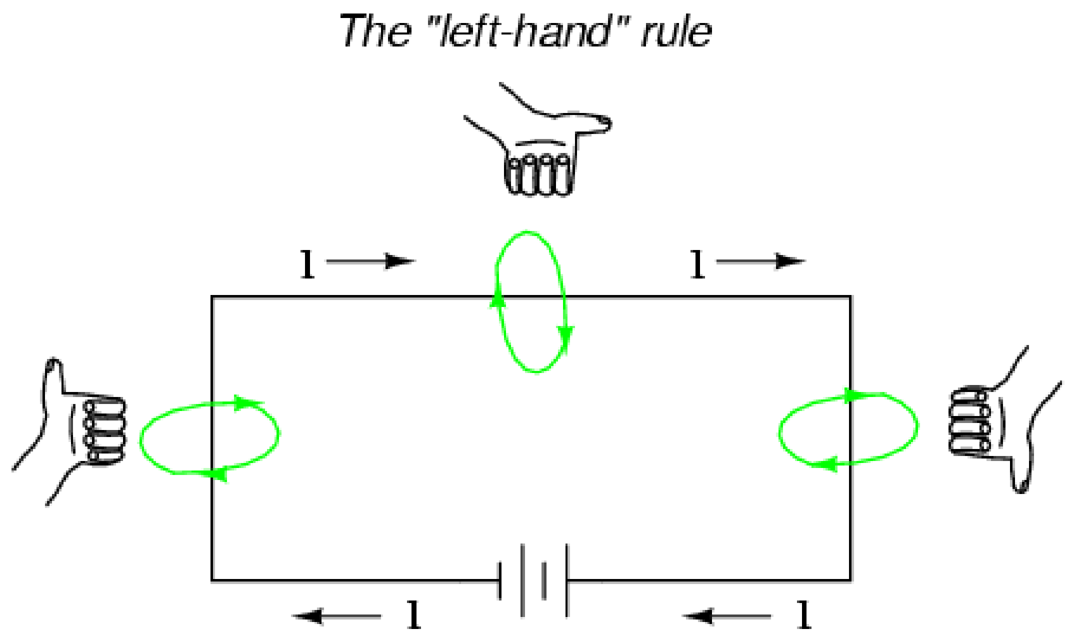
$$E_w = qV$$
$$8 \times 10^{-16} = 1.6 \times 10^{-19} \times V$$
$$V = 5000V$$

(b) 2nd set of plates (Vertical plates) move the beam left and right. These should be uncharged as there is no movement of the beam in this plane

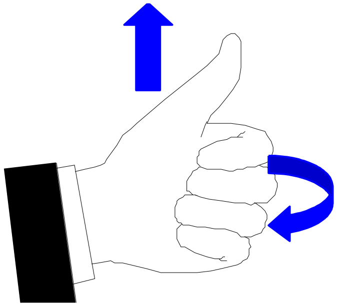
1st set of plates (Horizontal plates) move the beam up and down. The electrons will be attracted to the positive plate so the lower horizontal plate should be positive compared to the top plate and to move the beam two squares down requires double the pd than to move it one square down.

In 1820 the Danish physicist Oersted discovered that a magnetic compass was deflected when an electrical current flowed through a nearby wire. This was explained by saying that when a charged particle moves a magnetic field is generated. In other words, a wire with a current flowing through it (a current-carrying wire) creates a magnetic field.

The magnetic field around a current-carrying wire is circular. For electron flow, the direction of the field can be found by using the left-hand grip rule.



LEFT HAND GRIP RULE



Thumb = direction of electron flow

Fingers =direction of the magnetic field

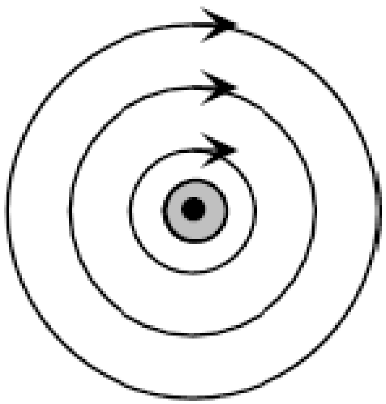
Moving charges experience a force in a magnetic field

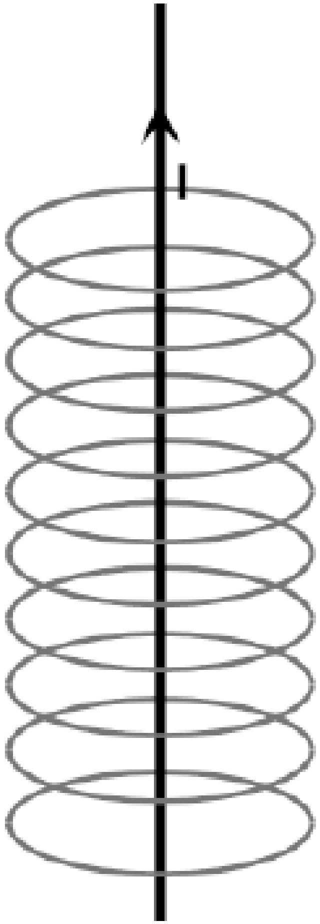
Summary

A stationary charge creates an electric field.

A moving charge also creates a magnetic field

FOR ELECTRON FLOW





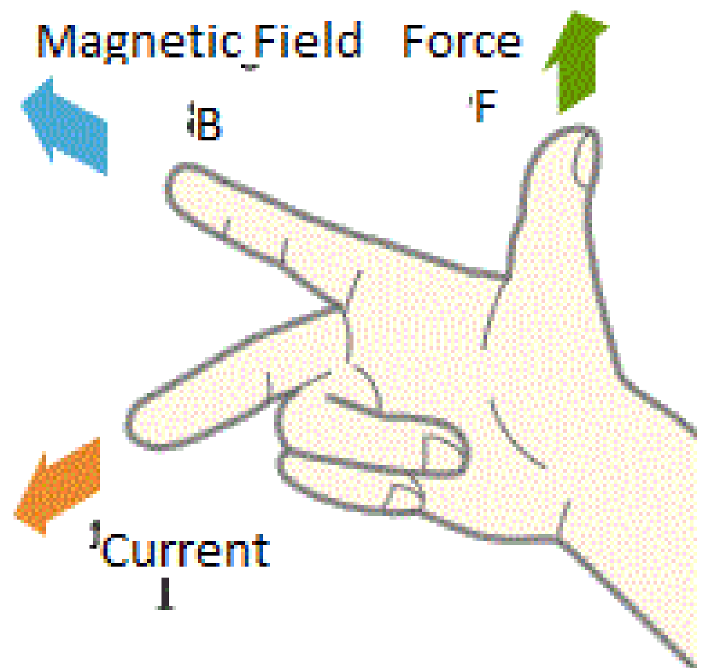
Where:

First Finger is the magnetic Field

seCond Finger is the Current (eleCton flow)

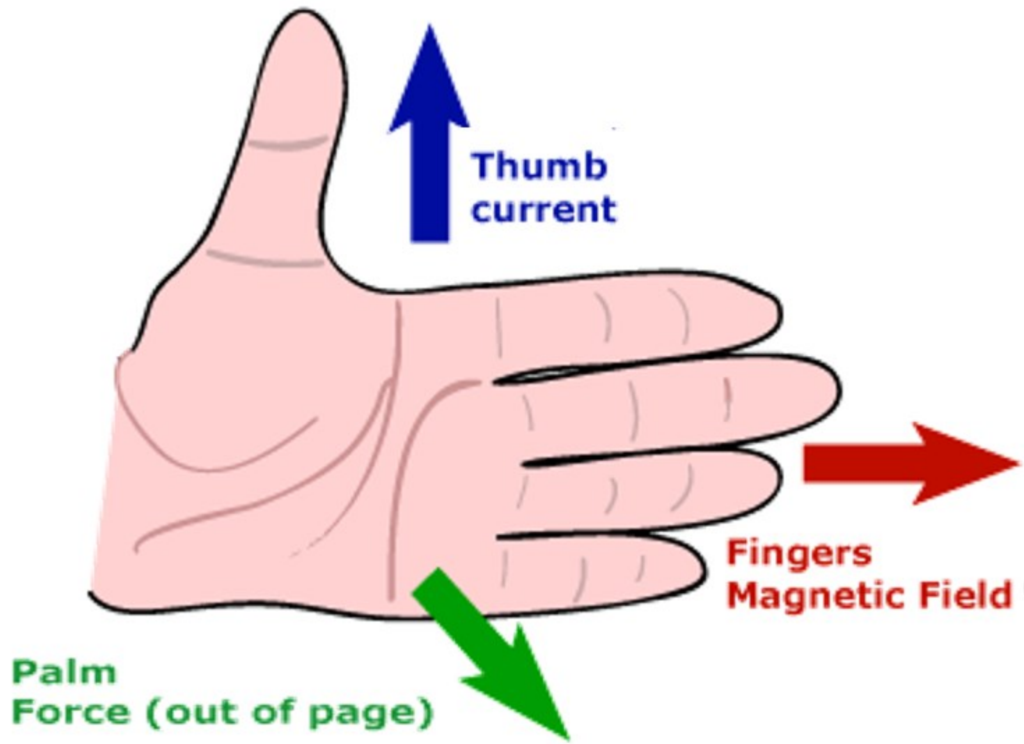
ThuMb is the Motion

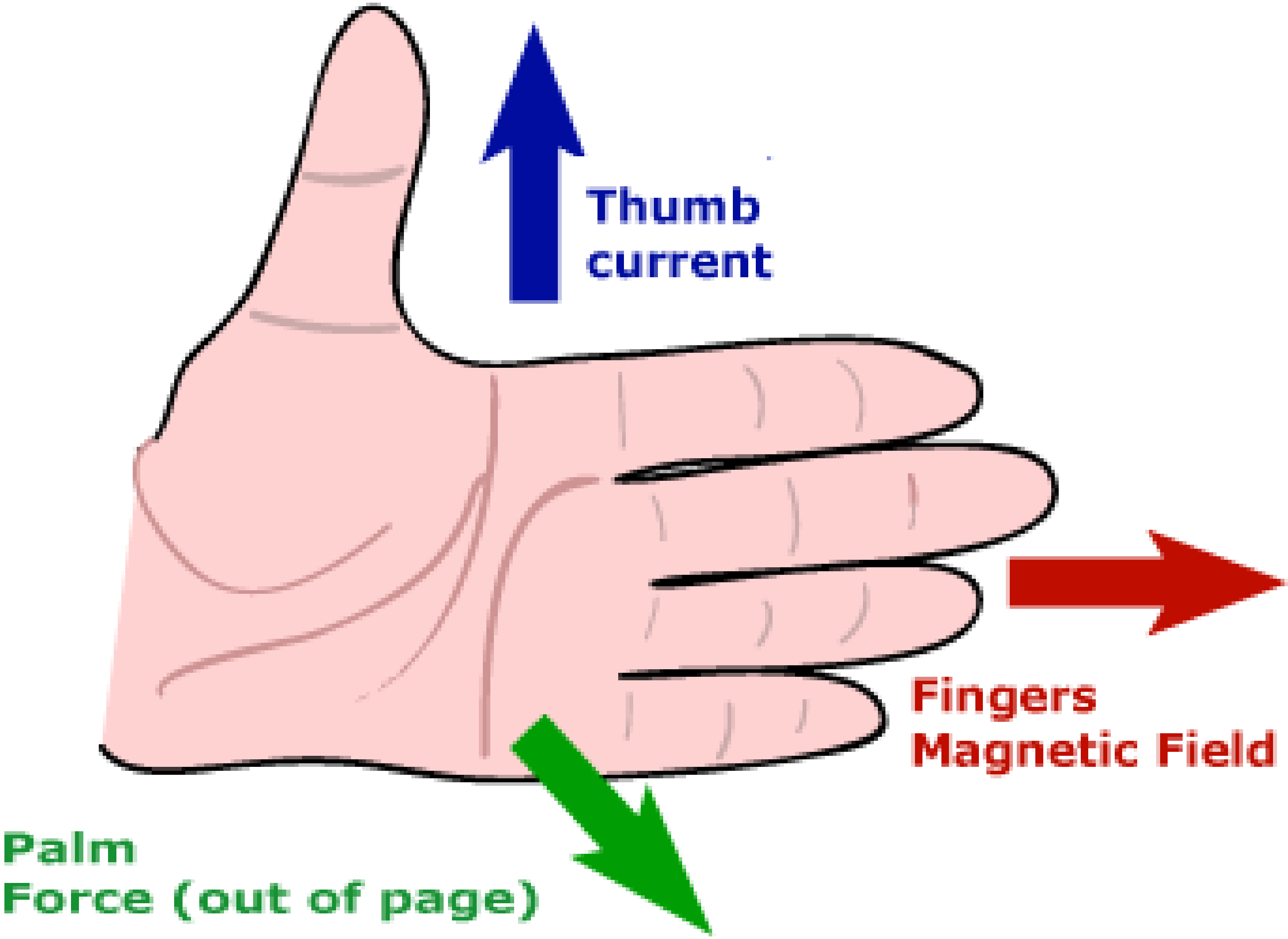
Right Hand Motor Rule

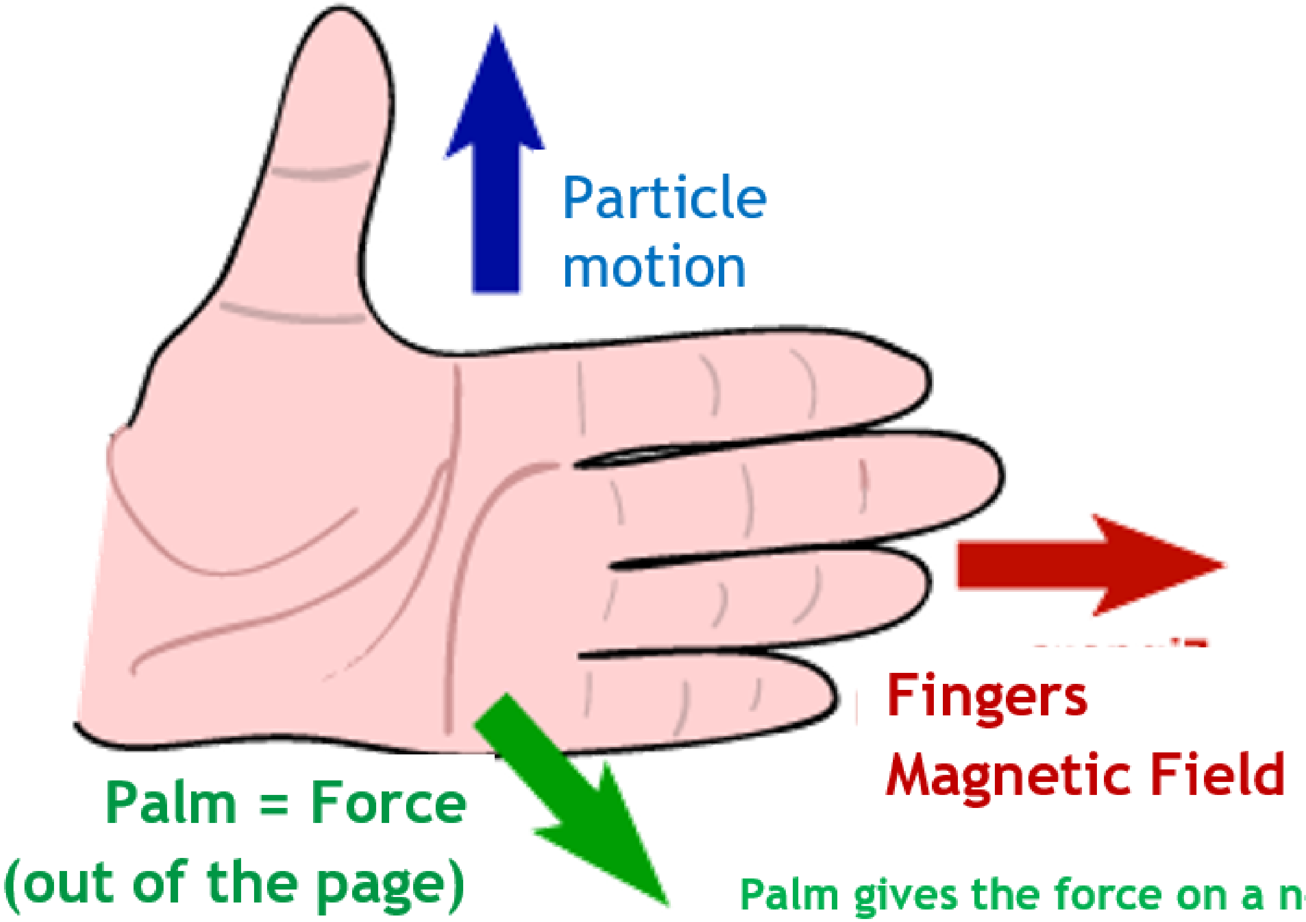


LEFT HAND SLAP METHOD.

- **Alternatively,** the Left-hand Slap Rule **where the four fingers of the left point in the direction of the magnetic field B and the thumb points in the direction of the electron current I, the direction of slapping would be the direction of force F on the conductor.**

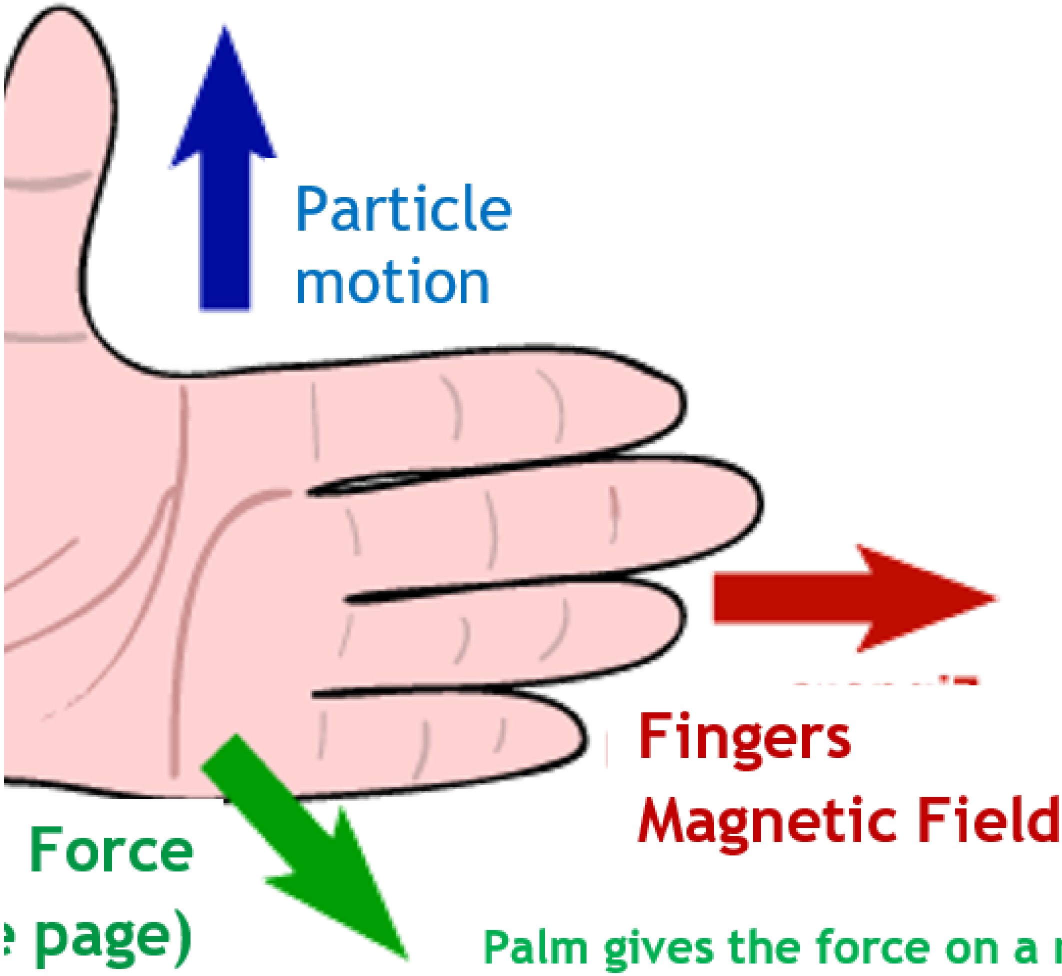



Thumb
current
Fingers
Magnetic Field
Palm
Force (out of page)



Palm gives the force on a negative particle.
Backhand gives the force on a positive particle, and it's more painful on the backhand

LET'S DO THE FOOL PROOF SYSTEM OF REMEMBERING WITH LEFT HAND



Palm gives the force on a negativ
particle.
Backhand gives the force on a positive particle, and it's more painful on the backhand


- partic
Not as much pain (negative)
Force
HIT ON TABLE
FIELD
SLAP NEGATIVE
Out of the hand!

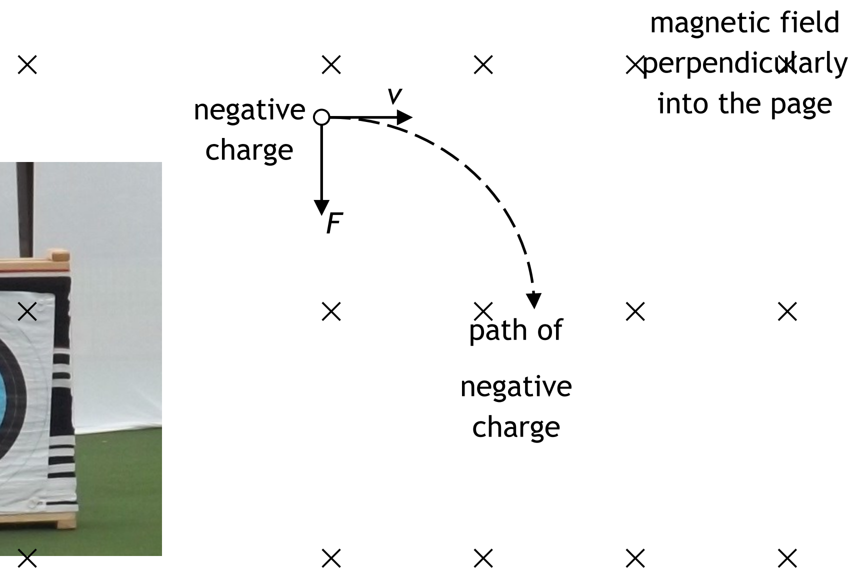
As we are working on 2D paper for a 3D model we have to show the extra dimension of going in and coming out of the paper. To distinguish these we use the arrow model. If an arrow was coming towards you, you would see the point. A great big dot (duck)! If the arrow was going away from you, you would notice the feathers arranged as a cross.

arrow coming towards you (out of the page)

•

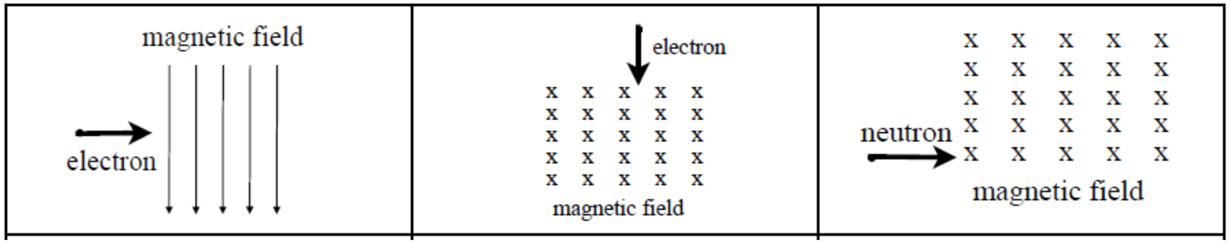
arrow going away from you (into the page)

×



The motor rules are also used to determine the direction of spin of the coil in an electric motor

Copy the diagrams below and describe the movement of the particle in the magnetic field.



Using the same magnetic fields as shown above replace each of the particles with an alpha particle. Describe the motion of the alpha particle due to the force from each field.

Complete the tutorial sheet