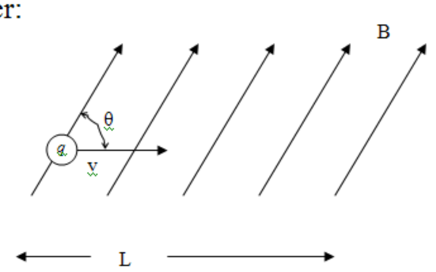
Lesson 4
Magnetic Force on Moving Charges

A current-carrying conductor placed in a magnetic field will experience a force. Moving charges do not need to be bound in a wire for this to happen.

Consider:



This charged particle, q, will constitute a current if ‘n’ particles pass a certain point in a given time Δt.

Current is given by: $I = \frac{nq}{t} = \frac{\text{charge}}{\text{time}}$

The distance L is given by:

Distance = speed × time

$L = v\Delta t$

Thus,

$F = BIL\sin\theta$ becomes

$$F = B\left(\frac{nq}{t}\right)(v\Delta t)\sin\theta$$

For a single charge, n = 1 and

$$F = qvB\sin\theta$$

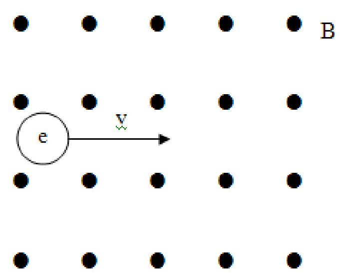
where,

F = the magnetic force on an individual moving charge (N)
q = charge (C)
v = velocity of the charge (m/s)
B = magnetic field strength (T)
θ=angle between velocity vector and direction of magnetic field

Note that this force is the strongest when the current is perpendicular to the magnetic field and weakest (zero) when it is parallel to the magnetic field.

The direction of the force applied to each moving charge can be found by using the left hand rule for the motor principle.

Example:
Consider the diagram shown. In what direction will the electron be deflected?



See diagram p. 649 in text.

Example:
A proton having a speed of 5.0×10^6 m/s in a magnetic field feels a force of 8.0×10^{-14} N toward the west when it moves vertically upward. When moving horizontally in a northerly direction, it feels zero force. What is the magnitude and direction of the magnetic field in this region? (The charge on a proton is 1.6×10^{-19} C)

Solution:
Since we are dealing with a proton we use the right hand rule. Since the proton feels no force when moving north, the magnetic field must be in a north-south direction. The right hand rule tells us that B must point toward the north in order to produce a force to the west when the proton moves upward. (thumb points up, palm faces west, fingers face north).

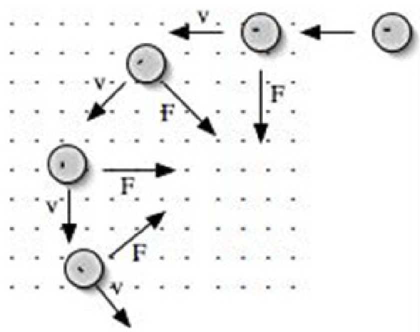
The magnitude of the magnetic field is:

See examples 6, 7 on p. 649 of text.

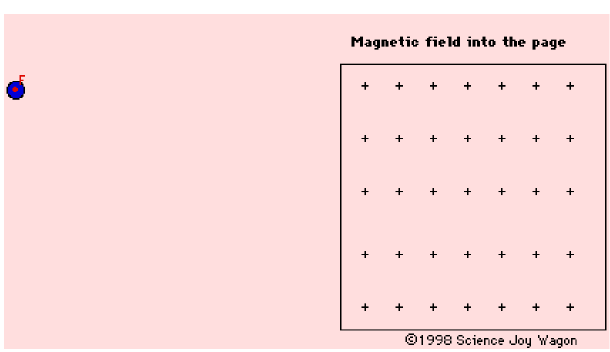
Centripetal Magnetic Force

The path of a charged particle moving in a plane perpendicular to a uniform magnetic field is a circle.

Consider:



Note the force on the electron (using left hand rule). Since the force is always perpendicular to the velocity, the magnitude of the velocity does not change but the particle changes direction and moves in a circular path, with a centripetal acceleration. The force is directed toward the centre of the circle at all points. So in this case the electron will move in a counterclockwise circular path.



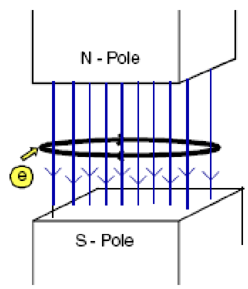
Thus,

$$F_{magnetic} = F_{centripetal}$$
$$qvB\sin\theta = \frac{mv^2}{r}$$
$$and \ \sin\theta = 1 \ so,$$
$$qvB = \frac{mv^2}{r}$$
$$r = \frac{mv}{Bq}$$

This formula allows us to calculate the radius of the circular path traced out by charged particles injected into magnetic fields.

Example:
An electron travels at 2.0×10^7 m/s in a plane perpendicular to a 0.010 T magnetic field. Describe its path.

We could also conceptualize this as shown:



The permanent and induced magnetic fields interact to force the electron in a certain direction as shown.

If the electron is shot in at an angle other than 90°, it will spiral in the magnetic field.

Spiral Path

See example 8, p. 654 in text.