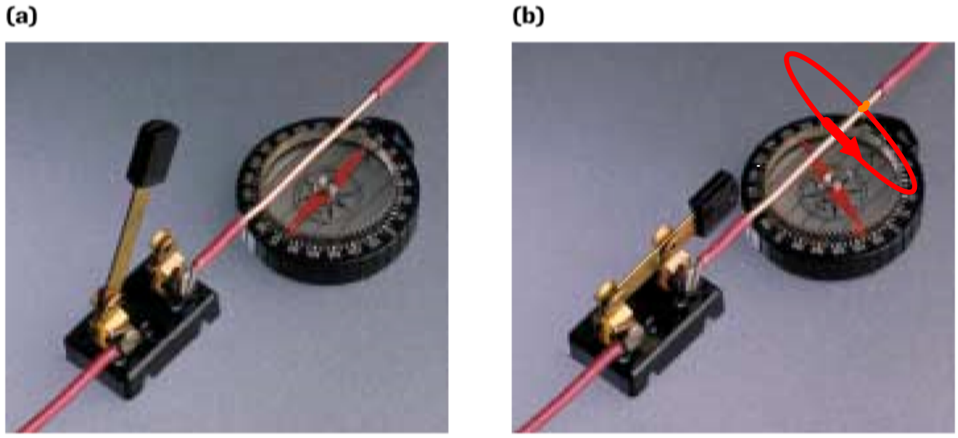
Sec. 8.2 - Magnetic Force on MOVING Charge

Learning Goal: By the end of today I will be able to determine the magnitude and direction of the magnetic force on a particle in a magnetic field.

If a current can create a magnetic force, then it stands to reason that a magnetic force can not only create a current, but affect it as well.



off on

Conventional Flow - electricity (positive charge) flows from + to -

In conventional flow, a positive charge going to the right is equivalent to a negative charge going to the left.

Electron Flow - electrons flows from - to +

Electric Field Strength Review

$$\varepsilon = \frac{F}{q}$$

- force was dependent on amount of charge

- force direction was in the same direction as the field lines (attractive or repulsive), for both point or uniform fields

Measuring Magnetic Fields

The magnitude of the magnetic force F_M on a charged particle

- is directly proportional to the magnitude of the magnetic field B, the velocity v, and the charge q of the particle.
- depends on the angle theta between the magnetic field B and the velocity v
- When theta is 90° (the particle is moving perpendicular to the field lines), the force is at a maximum,and when theta is 0° or 180° (particle is moving parallel to the field lines), the force vanishes.

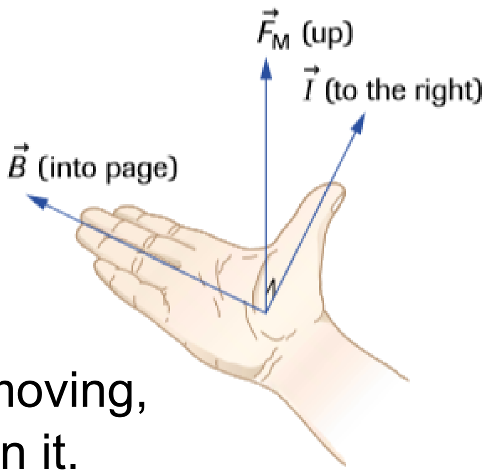
Combining these factors gives

$$F_M = qv\beta\sin\theta$$

Note: this model is for conventional flow and with a positive charge.

where F_M is the magnitude of the force on the moving charged particle, in newtons; q is the amount of charge on the moving particle,in coulombs; v is the magnitude of the velocity of the moving particle,in metres per second; B is the magnitude of the magnetic field strength,in teslas (SI unit,T; 1 T = 1 kg/C s); and theta is the angle between v and B

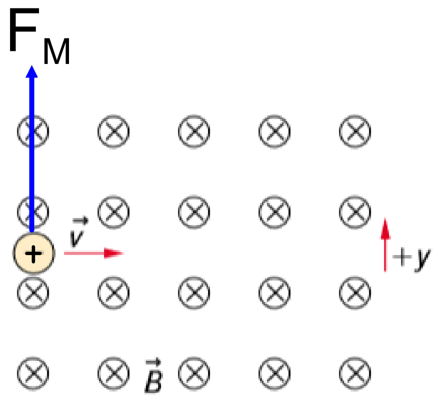
$$1T = \frac{1kg}{C \cdot s}$$

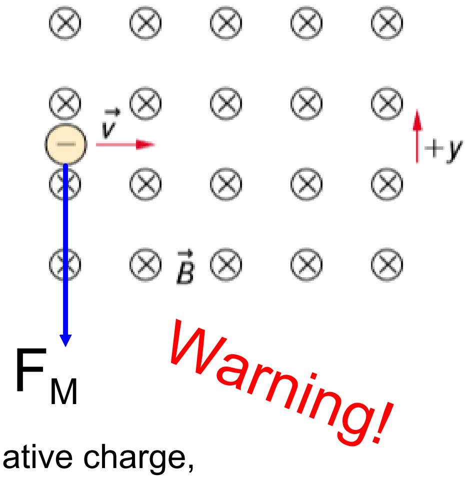


Note: if the charge is NOT moving, there is no magnetic force on it.

Calculus students will recognize the Cross Product here.

So what does this interaction look like?





positive charge,

conventional flow for velocity (+ to -)

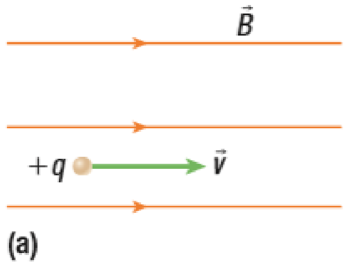
follows right hand rule

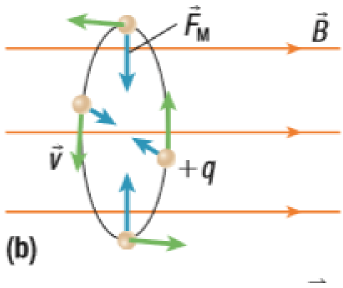
negative charge,

conventional flow for velocity (+ to -)

follows right hand rule with the exception that direction of velocity is taken as the opposite to take into account the negative charge of the particle

Charges in a Uniform Magnetic Field

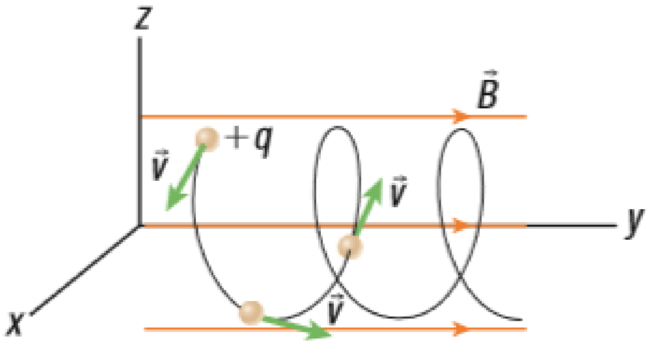




v is parallel to B = no F_M

v is perpendicular to B = maximum F_M

If v has velocity components that are both parallel and perpendicular, you get a combination of both cases.

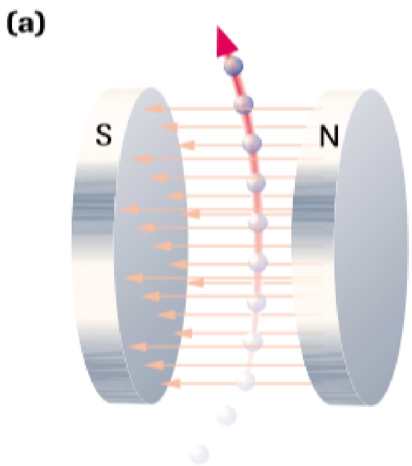


The perpendicular case: v is 90° to B

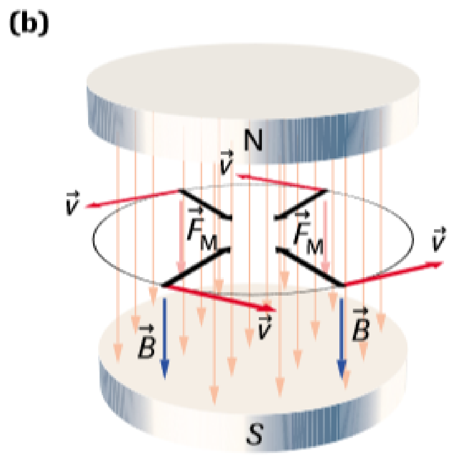
Let us now take a closer look at the trajectory of a charged particle in a magnetic field. When F_M is always perpendicular to v, it is a purely deflecting force,meaning it changes the direction of v but has no effect on the magnitude of the velocity or speed.

This is true because no component of the force acts in the direction of motion of the charged particle.

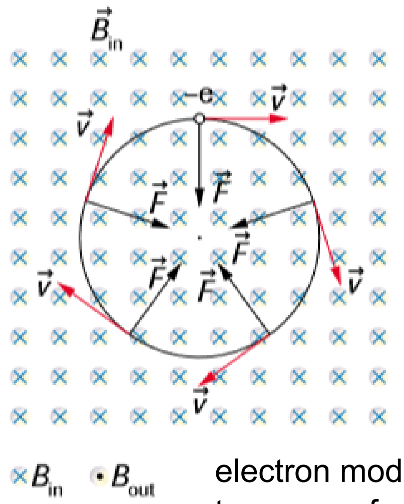
As a result,the magnetic field does not change the energy of the particle and does no work on the particle.



positive particle



positive particle



electron model - don't forget to reverse force direction

$$a_c = \frac{v^2}{r}$$ Centripetal acceleration and force $$F_c = \frac{mv^2}{r}$$

Example

An electron accelerates from rest in a horizontally directed electric field through a potential difference of 46 V. The electron then leaves the electric field, entering a magnetic field of magnitude 0.20 T directed into the page (**Figure 7**).

(a) Calculate the initial speed of the electron upon entering the magnetic field.

(b) Calculate the magnitude and direction of the magnetic force on the electron.

(c) Calculate the radius of the electron's circular path.

Solution

$\Delta V = 46\text{ V}$

$B = 0.20\text{ T} = 0.20\text{ kg/C·s}$

$m_e = 9.11 \times 10^{-31}\text{ kg}$ (from Appendix C)

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

$v = ?$

$F_M = ?$

$r = ?$

(a) The electric potential energy lost by the electron in moving through the electric potential difference equals its gain in kinetic energy:

$$-\Delta E_E = \Delta E_K$$

(b) $F_M = qvB\sin\theta$

(c) Since the magnetic force is the only force acting on the electron and it is always perpendicular to the velocity, the electron undergoes uniform circular motion. The magnetic force is the net (centripetal) force:

$$F_M = F_c$$

$$qvB = \frac{mv^2}{r} \quad \text{(since } \sin 90^\circ = 1\text{)}$$

Example

A proton is moving along the x-axis at a speed of 78 m/s. It enters a magnetic field of strength 2.7 T. The angle between the proton's velocity vector and the magnetic field is 38° (**Figure 6**). The mass of a proton is 1.67×10^{-27} kg.

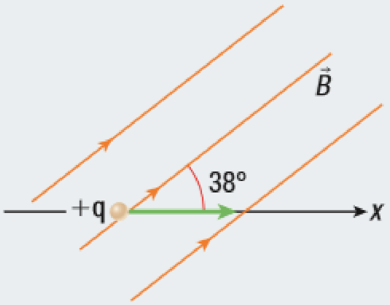


Figure 6

(a) Calculate the initial magnitude and the direction of the magnetic force on the proton.

(b) Determine the proton's initial acceleration.

Solution

(a) **Given:** $q = 1.60 \times 10^{-19}$ C; $v = 78$ m/s; $B = 2.7$ T; $\theta = 38°$

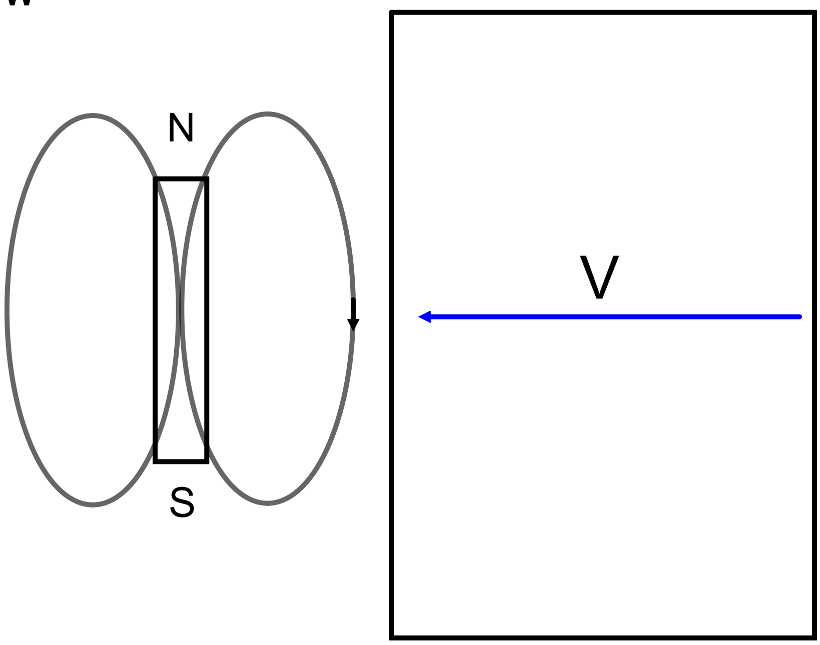
(b) **Given:** $F_M = 2.075 \times 10^{-17}$ N; $m = 1.67 \times 10^{-27}$ kg

Required: acceleration, a

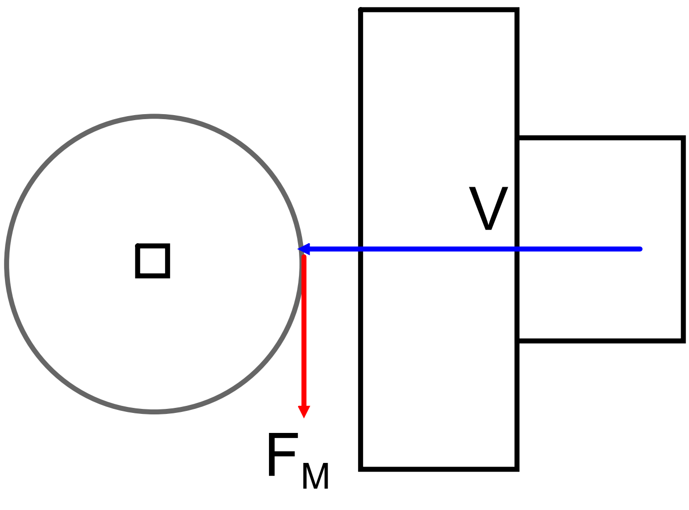
Analysis: $a = \dfrac{F_M}{m}$

Monitor and Magnet Demo

Side View



Plan View



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SUMMARY Magnetic Force on Moving Charges

- A current can exert a force on a magnet, and a magnet can exert a force on a current.
- $F_M = qvB \sin \theta$
- The direction of the magnetic force is given by the right-hand rule.
- The speed of an electron in a cathode-ray tube can be determined with the help of magnetic deflecting coils and electric deflecting plates. The same apparatus then gives the charge-to-mass ratio of the electron. Combining this determination with the charge of an electron from the Millikan oil-drop experiment yields the mass of the electron.

Interesting Reading pg 396 - 401

- Charge to Mass Ratio

- Field Theory

- Van Allen Belts

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Homework

Read 392 - 403

page 396 #2, 3, 4

page 402-03 #1, 4, 5, 12