Lecture (06)

Magnetism (I)

By:

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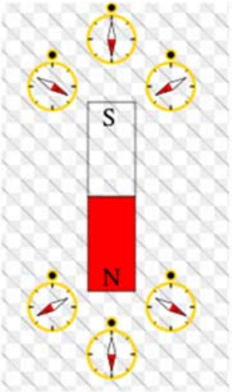
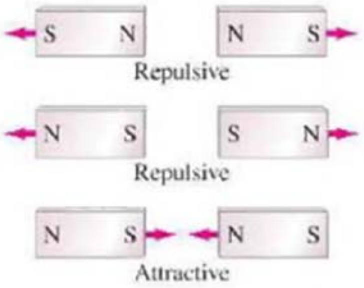
Magnets and Magnetic Fields

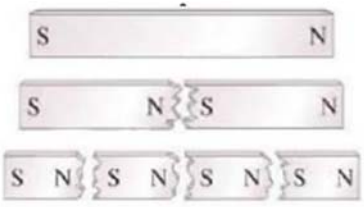
- Any magnet, has two ends or faces, called poles, which is where the magnetic effect is strongest
- If magnet bar hocked in free space, one pole of the magnet will always point toward the north.
- The pole of a freely suspended magnet that points toward geographic north is called the north pole of the magnet.
- The other pole points toward the south and is called the south pole



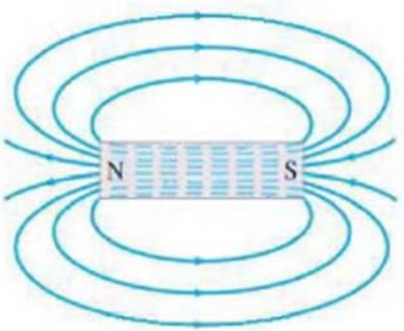
- when two magnets are brought near one another, each exerts a force on the other
  - like poles repel,
  - Unlike poles attract.
- can be felt even when the magnets don't touch



- *<u>magnetic poles & electric charge.</u>*
- They are very different.
- One important difference is that a positive or negative electric charge can easily be isolated.
- But an isolated single magnetic pole has never been observed. If a bar magnet is cut in half, you do not obtain isolated north and south poles.
- Instead, two new magnets are produced,

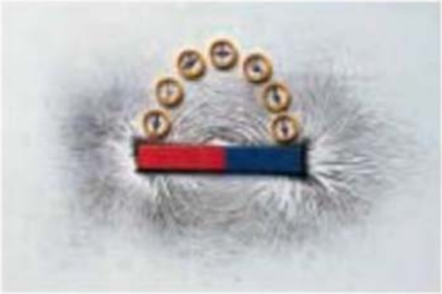


- Only iron and a few other materials, such as cobalt, nickel, gadolinium, and some of their oxides and alloys, show strong magnetic effects, called <u>ferromagnetic</u>
- a magnetic field is surrounding a magnet

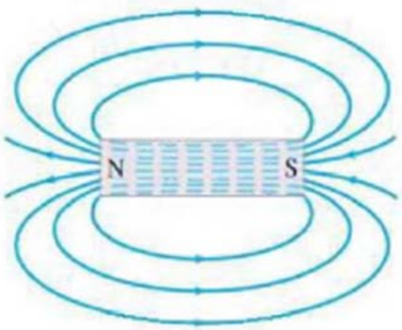


The force one magnet exerts on another can then be described as the interaction between one magnet and the magnetic field of the other.

- The *direction* of the magnetic field at a given point can be defined as the direction that the north pole of a compass needle would point if placed at that point
- the lines always point out from the north pole and in toward the south pole of a magnet (the north pole of a magnetic compass needle is attracted to the south pole of the magnet).

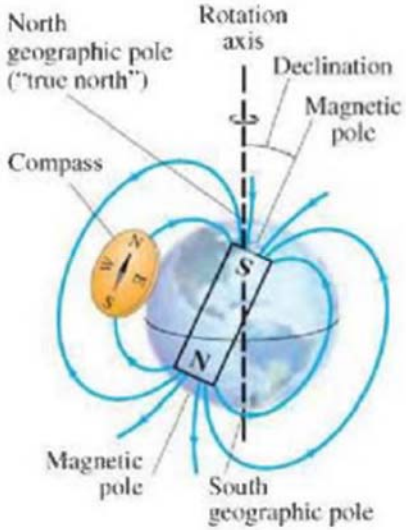


- Magnetic field lines continue inside a magnet, magnetic field lines always form closed loops, unlike electric field lines that begin on positive charges and end on negative charges

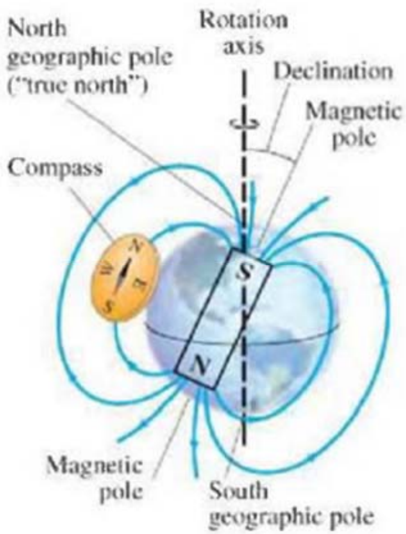


Earth's Magnetic Field

- The pattern of field lines is as if there were an imaginary bar magnet inside the Earth.
- Since the north pole (N) of a compass needle points north, the Earth's magnetic pole which is in the geographic north is magnetically a south pole

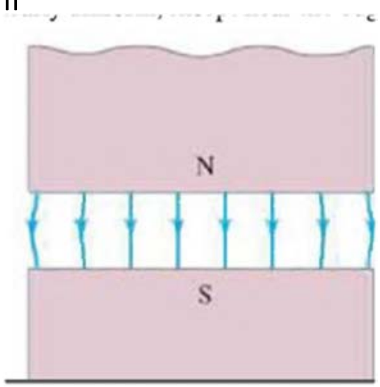


- The Earth's magnetic poles do not coincide with the *geographic* poles (which are on the Earth's axis of rotation).
- The north magnetic pole, for example, is in the Canadian Arctic,' about 900 km from the geographic north pole, or "true north."
- difference between magnetic north and true (geographical) north is called the magnetic declination.



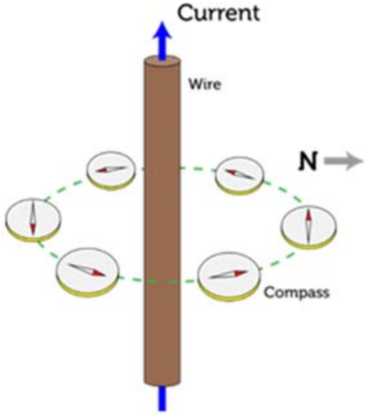
Uniform Magnetic Field

- field between two flat parallel pole pieces of a magnet is nearly uniform if the area of the pole faces is large compared to their separation,

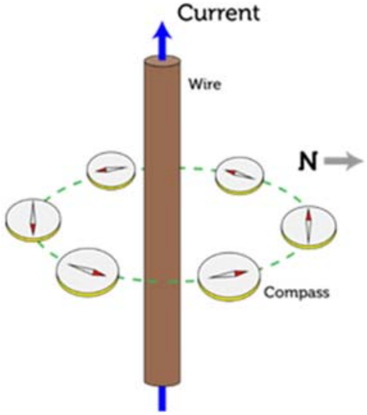


Electric Currents Produce Magnetic Fields

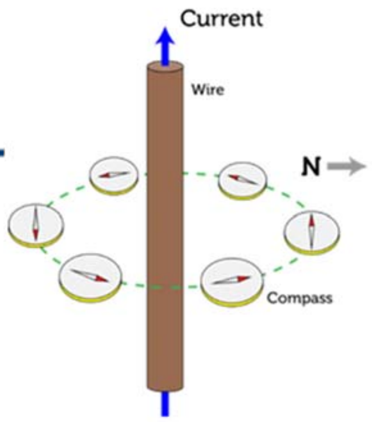
- when a compass needle is placed near a wire, the needle deflects when the wire is connected to voltage source and carries current, so an electric current produces a magnetic field.
- A compass needle placed near a straight section of current-carrying wire experiences a force, causing the needle to align tangent to a circle around the wire,

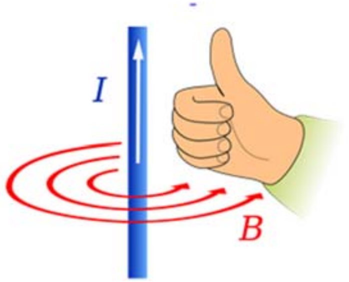


- the magnetic field lines produced by a current in a straight wire are in the form of circles with the wire at their center.
- The direction of these lines is indicated by the north pole of the compasses

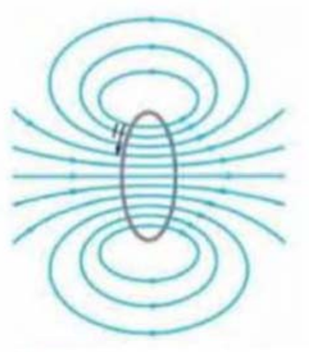


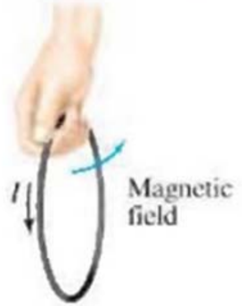
- **right-hand rule:**
- grasp the wire with your right hand so that your thumb points in the direction of the conventional (positive) current; then your fingers will encircle the wire in the direction of the magnetic field,





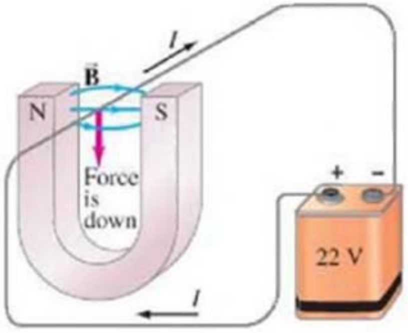
- The magnetic field lines due to a circular loop of current-carrying wire can be determined using a compass.
- the right-band rule can be used



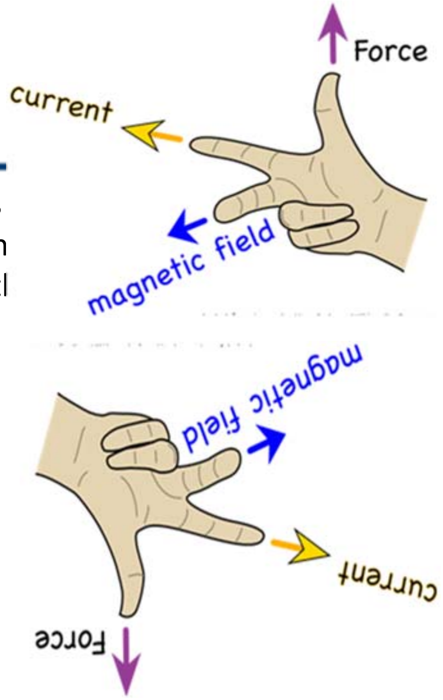


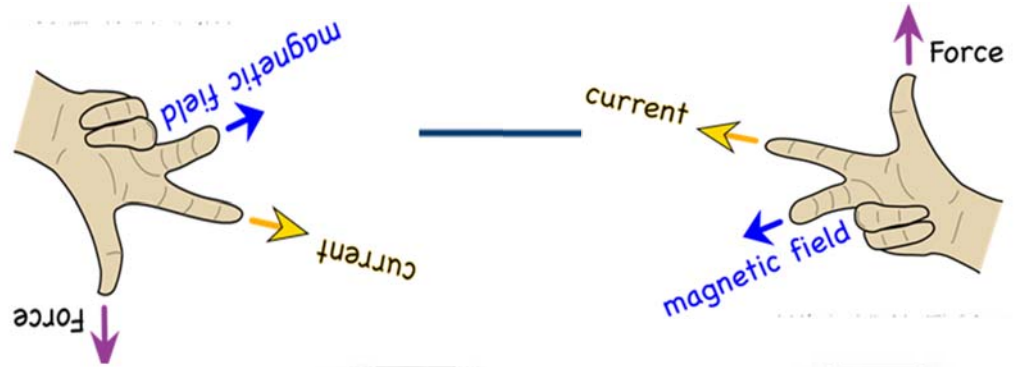
Force on an Electric Current in a Magnetic Field; Definition of B

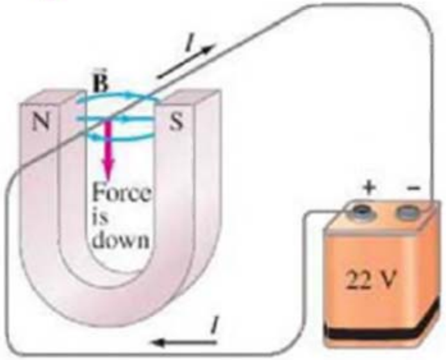
- electric current exerts a force on a magnet
- By Newton's third law, we might expect the reverse to be true as well: we should expect that *a magnet exerts a force on a current-carrying wire.*
- Suppose a straight wire is placed in the magnetic field between the poles of a horseshoe magnet as shown
- When a current flows in the wire, force is exerted on the wire.

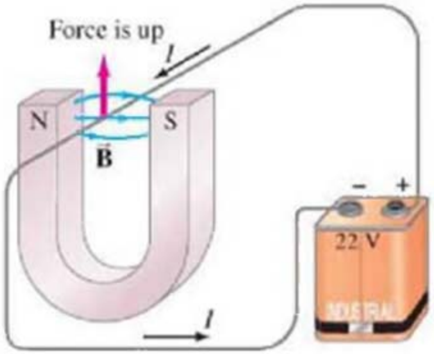


- the direction of the force is always perpendicular to the direction of th current and also perpendicular to t direction of the magnetic field.



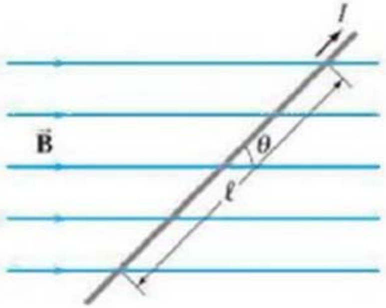






- the magnitude of the force is directly proportional to the current *I* in the wire, and to the length *l* of wire exposed to the magnetic field
- if the magnetic field θ is made stronger, the force is found to be proportionally greater
- force also depends on the angle θ between the current direction and the magnetic field

$$F \propto I\ell B \sin\theta.$$



- When the current is perpendicular to the field lines (θ = 90°), the force is strongest.
- When the wire is parallel to the magnetic field lines *(θ = 0°)*,

$$F = I\ell B \sin\theta.$$

- If the direction of the current is perpendicular to the field B *(θ* = 90°), then the force is

$$F_{\max} = I\ell B$$

- If the current is parallel to the field *(θ = 0°*)the force is zero.

- The relation between the force F on a wire carrying current *I,* and the magnetic field B that causes the force, can be written as a vector equation.

$$\vec{\mathbf{F}} = I\vec{\boldsymbol{\ell}} \times \vec{\mathbf{B}};$$

- applies if the magnetic field is uniform and the wire
- If B is not uniform,

$$d\vec{\mathbf{F}} = I\, d\vec{\boldsymbol{\ell}} \times \vec{\mathbf{B}},$$

- *df* is the infinitesimal force acting on a differential length *dl* of the wire.

Example 01

$F = I\ell B \sin\theta.$

- A wire carrying current *I* is perpendicular to a magnetic field of strength *B.* Assuming a fixed length of wire, which of the following changes will result in decreasing the force on the wire by a factor of 2?

(a) Decrease the angle from 90° to 45°;

(*b*) decrease the angle from 90° to 30°;

(c) decrease the current in the wire to *1/2;*

(*d)* decrease the magnetic field strength to *B/*2;

(e) none of these will do it.

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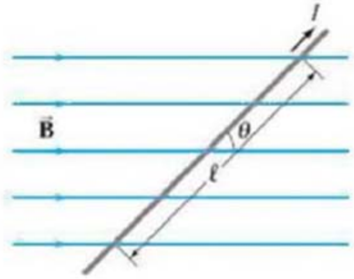
Example 02

- Magnetic force on a current-carrying wire.
- A wire carrying a 30-A current has a length *l* = 12 cm between the pole faces of a magnet at an angle θ = 60° .The magnetic field is approximately uniform at 0.90 T.
- We ignore the field beyond the pole pieces.
- What is the magnitude of the force on the wire?



- $I = 30\ A$
- $l = 0.12\ m$
- $B = 0.9\ T$
- $\theta = 60$

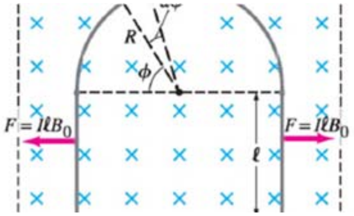
$$F = I\ell B \sin\theta = (30\ \mathrm{A})(0.12\ \mathrm{m})(0.90\ \mathrm{T})(0.866) = 2.8\ \mathrm{N}.$$

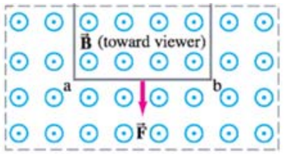
example 03

- A straight power line carries 30 A and is perpendicular to the Earth's magnetic field of 0.50 X 10^{-4} T. What magnitude force is exerted on 100 m of this power line?

- $I = 30\ A$
- $B = 0.5\ \times 10^{-4}\ T$
- $l = 100m$
- $\theta = 90$
- $F = BIL\sin\theta = 30 \times 100 \times 0.5 \times 10^{-4} = 0.15\ N$

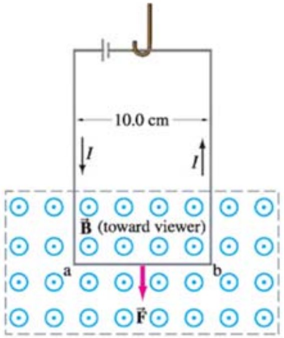
- On a diagram, when we want to represent an electric current or a magnetic field that is pointing out of the page (toward us) or into the page, we use ◉ or ⊗ , respectively.
- The is meant to resemble the tip of an arrow pointing ◉directly toward the reader, whereas the r ⊗ resembles the tail of an arrow moving away



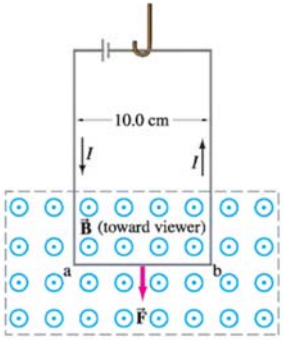


Example 04

- **Measuring a magnetic field.** A rectangular loop of wire
- hangs vertically as shown in Fig.
- A magnetic field **B** is directed horizontally,
- perpendicular to the wire, and points out of the page at all points as represented
- by the symbol ◉. The magnetic field **B** is very nearly uniform along the horizontal portion of wire ab (length f = 10.0cm) which is near the center of the gap of a large magnet producing the (field. The top portion of the wire loop is free of the field. The loop hangs from a balance which measures a downward magnetic force (in addition to the gravitational force) of *F* = 3.48 X 10^{-2} N
- when the wire carries a current *i* = 0.245 A. What is the magnitude of the magnetic field *B?*

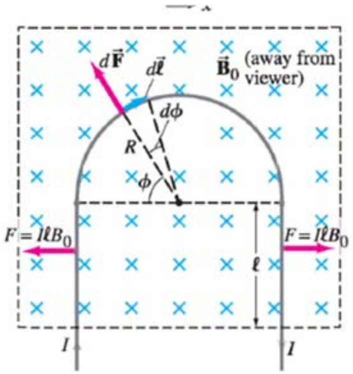


- $l = 0.1\ m$
- $F = 3.48 \times 10^{-2}\ N$
- $i = 0.245\ A$
- $\theta = 90$
- $B = \frac{F}{Il\sin\theta} = \frac{3.48 \times 10^{-2}}{0.1 \times 0.245 \times 1} = 1.41\ T$



Example 05

- Magnetic force on a semicircular wire. A rigid wire, carrying a current *I,* consists of a semicircle of radius *R* and two straight portions as shown in Fig.
- The wire lies in a plane perpendicular to a uniform magnetic field B_0.
- Note choice of *x* and *y* axis.
- The straight portions each have length *i* within the field.
- Determine the net force on the wire due to the magnetic field B_0.



- The forces on the two straight sections are equal *(= IiB₀)* and in opposite directions, so they cancel.
- We divide the semicircle into short lengths

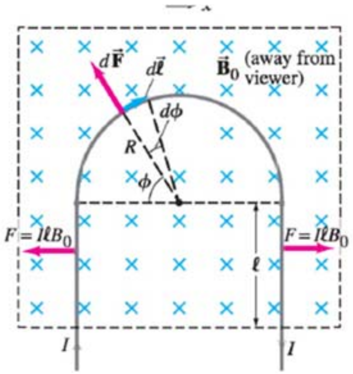
$$d\ell = R\,d\phi$$

$$d\vec{\mathbf{F}} = I\,d\vec{\boldsymbol{\ell}} \times \vec{\mathbf{B}},$$

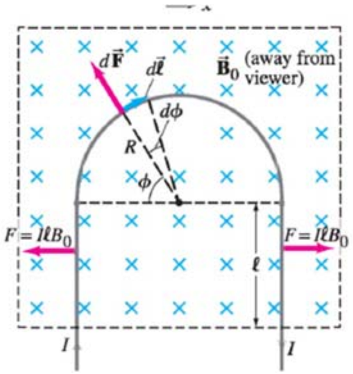
- where *dF* is the force on the length

$$d\ell = R\,d\phi$$

- the angle between *dl* and B_0 is 90° (so sin θ = 1 in the cross product)



- The *x* component of the force *dF* on the segment *d l* shown, and the *x* component of *dF* for a symmetrically located *dl* on the other side of the semicircle, will cancel each other
- **Thus for the entire semicircle there will be no *x* component of force**
- **the *y* components, each equal to *dF* = sin dØ,**



$$F = \int_0^{\pi} dF \sin\phi$$

$$F = IB_0R\int_0^{\pi} \sin\phi \, d\phi$$

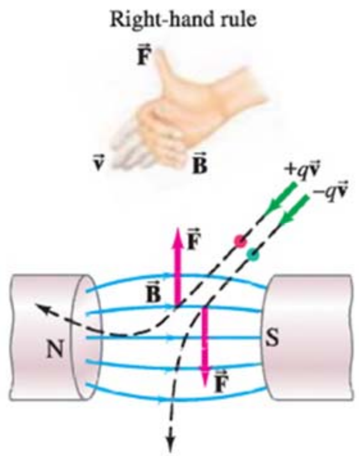
$$F = -IB_0R\cos\phi\Big|_0^{\pi}$$

$$F = 2IB_0R,$$

- with direction vertically upward along they axis

Force on an Electric Charge Moving in a Magnetic Field

- wire carrying a current experiences a force when placed in a magnetic field
- current in a wire consists of moving electric charges, the freely moving charged particles, would experience a force when passing through a magnetic field.
- If *N* a particles of charge *q* pass by a given point in time *t,* they constitute a current *I = Nq/t.*



- We let *t* be the time for a charge *q* to travel a distance ℓ in a magnetic field B;

$$I = Nq/t$$

- then where v is the velocity of the particle.

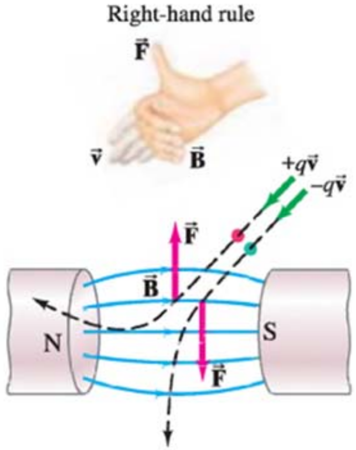
$$\vec{\ell} = \vec{v}t$$

- the force on these *N* particles is

$$\vec{F} = I\vec{\ell} \times \vec{B} =$$

$$(Nq/t)(\vec{v}t) \times \vec{B}$$

$$= Nq\vec{v} \times \vec{B}.$$



- The force on *one* of the *N* particles is then

$$\vec{F} = q\vec{v} \times \vec{B}.$$

- This gives the magnitude of the force on a particle of charge *q* moving with velocity v at a point where the magnetic field has magnitude *B.* The angle between v and B is θ

$$F = qvB\sin\theta.$$

- The force is greatest when the particle moves perpendicular to B (θ = 90°):

$$F_{\max} = qvB.$$

- The force is *zero* if the particle moves *parallel* to the field lines (θ = 0°).

Example 06

- Negative charge near a magnet.
- A negative charge —*Q* is placed at rest near a magnet.
- Will the charge begin to move?
- Will it feel a force?
- What if the charge were positive, *+Q1*

$$\vec{\mathbf{F}} = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}.$$

- No to all questions. A charge at rest has velocity equal to zero.
- Magnetic fields exert a force only on moving electric charges

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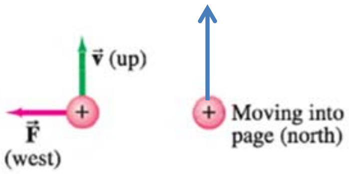
Example 07

- magnetic field exerts a force of 8.0 X 10^{14} N toward the west on a proton moving vertically upward at a speed of 5.0 X 10^6m/s. When moving horizontally in a northerly direction, the force on the proton is zero. Determine the magnitude and direction of the magnetic field in this region. (The charge on a proton is $q = +e$ = 1.6 X 10^{-19}C.)

$$\vec{\mathbf{F}} = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}.$$

- Since the force on the proton is zero when moving north, the field must be in a north or south direction.
- In order to produce a force to the west when the proton moves upward, the right-hand rule tells us that B must point toward the north.
- F = 8.0 X 10^{14}N
- V= 5.0 X 10^6m/s
- Q = 1.6 X 10^{-19}C
- B=F/(V x Q)= 0.1 T



Example 08

- Magnetic force on ions during a nerve pulse.
- Estimate the magnetic force due to the Earth's magnetic field on ions crossing a cell membrane during an action potential. Assume the speed of the ions is 10^{-2}m/s

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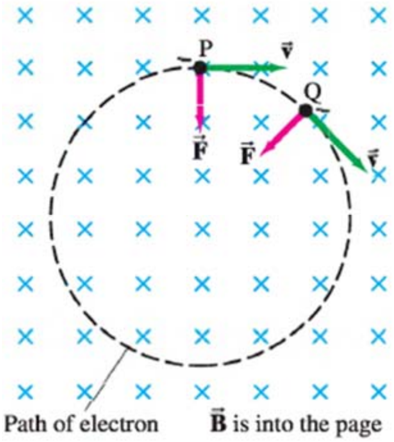
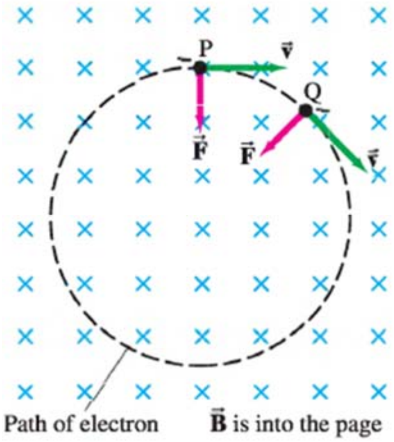
- $F = qvB$,
- **set the magnetic field of the Earth to be**
- **B = 10^{-4} T,**
- **and the charge $q = e = 10^{-19}$ C.**
- **$F = (1O^{-19}\ \text{C})(10^{-2}\ \text{m/s})(10^{-4}\ \text{T}) = 10^{-25}$N.**

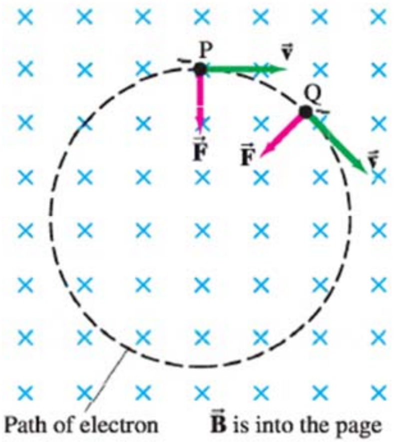
- The path of a charged particle moving in a plane perpendicular to a uniform magnetic field is a circle, the magnetic field is directed *into* the paper,
- An electron at point P is moving to the right, and the force on it at this point is downward as shown
- <u>Note: use right-hand rule and reverse the direction for negative charge</u>



- The electron is thus deflected toward the page bottom.
- **A moment later, say, when it reaches point Q, the force is still perpendicular to the velocity and is in the direction shown**
- **if the force on a particle is always perpendicular to its velocity v, the particle moves in a circle and has a centripetal acceleration $a = v^2/r$**

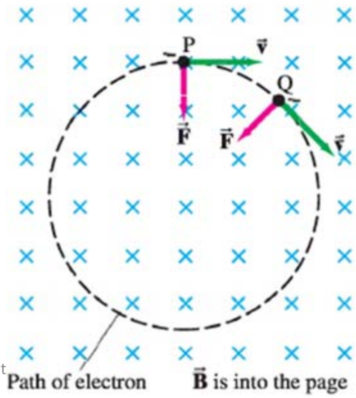


- Thus a charged particle moves in a circular path with constant centripetal acceleration in a uniform magnetic field moves clockwise.
- A positive particle in this field would feel a force in the opposite direction and would thus move counterclockwise



Example 09

- Electron's path in a uniform magnetic field. An electron travels at 2.0 X 10^7m/s in a plane perpendicular to a uniform 0.01 T magnetic field. Describe its path quantitatively.



- The electron moves at speed *v* in a curved path and so must have a centripetal acceleration *a = v2/r*
- the radius of curvature using Newton's second law.

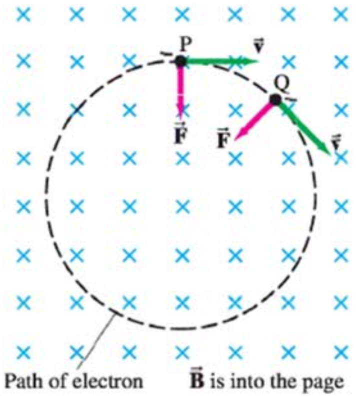
$$a = v^2/r$$

$$\Sigma F = ma$$

$$\sin\theta = 1 : F = qvB.$$

- sub

$$qvB = \frac{mv^2}{r}.$$



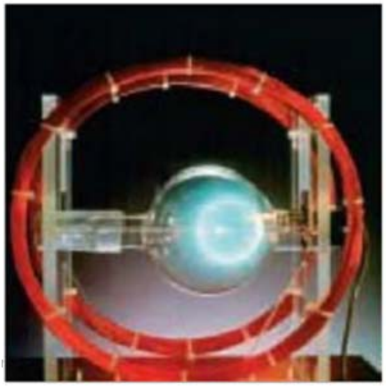
- We solve for *r* and find

$$r = \frac{mv}{qB}$$

- Since F is perpendicular to v, the magnitude of v doesn't change.
- From this equation we see that if B = constant, then *r* = constant, and the curve must be a circle

$$r = \frac{(9.1 \times 10^{-31}\,\text{kg})(2.0 \times 10^{7}\,\text{m/s})}{(1.6 \times 10^{-19}\,\text{C})(0.010\,\text{T})} = 1.1 \times 10^{-2}\,\text{m} = 1.1\,\text{cm}.$$

- The blue ring inside the glass tube is the glow of a beam of electrons that ionize the gas molecules. The red coils of current carrying wire produce a nearly uniform magnetic field, illustrating the circular path of charged particles in a uniform magnetic field.



Frequency of rotated practical in uniform electric field

- **The time *T* required for a particle of charge *q* moving with constant speed *v* to make one circular revolution in a uniform magnetic field B (-|- v) is**

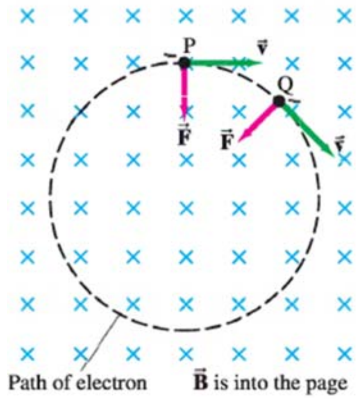
  T = 2 pi r/v,

- ***2 pi r :* is the circumference of its circular path**
- **But**

$$r = \frac{mv}{qB}.$$

- **then**

$$T = \frac{2\pi m}{qB}. \qquad f = \frac{1}{T} = \frac{qB}{2\pi m}.$$



$$f = \frac{1}{T} = \frac{qB}{2\pi m}.$$

- This is often called the cyclotron frequency of a particle in a field because this is the frequency at which particales revolve in a cyclotron

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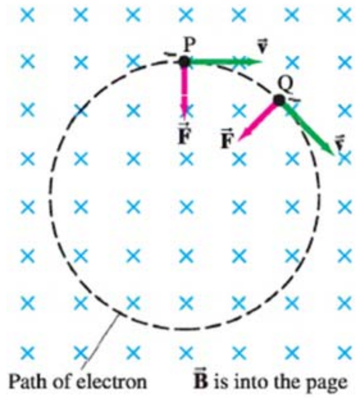
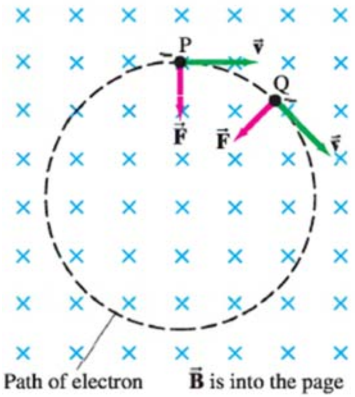
Example 09

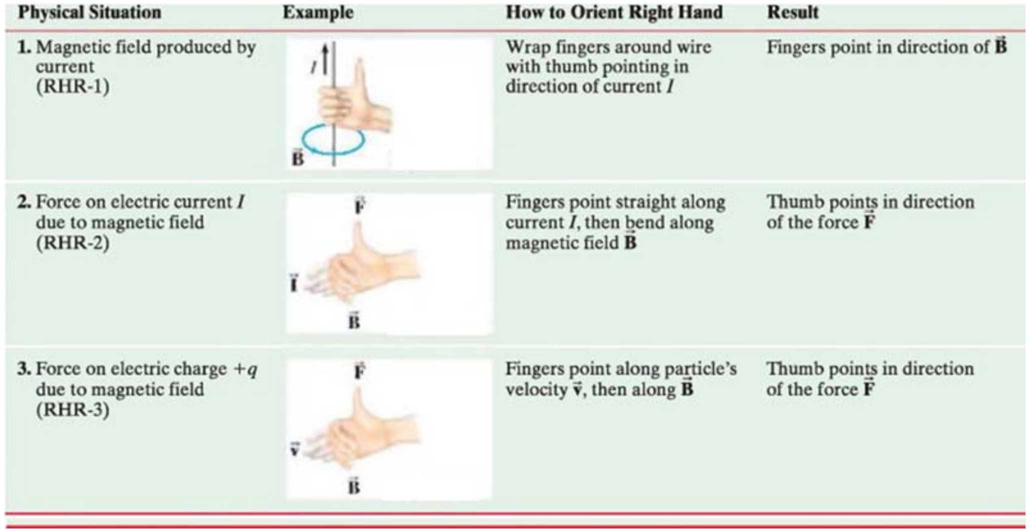
- Can a magnetic field be used to stop a single charged particle, as an electric field can?



- No, because the force is always *perpendicular* to the velocity of the particle and thus cannot change the magnitude of its velocity.
- It also means the magnetic force cannot do work on the particle and so cannot change the kinetic energy of the particle



Summary of Right-hand Rules (= RHR)

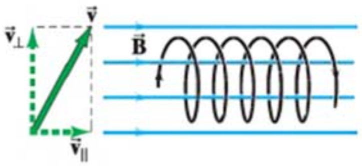


Physical Situation	Example	How to Orient Right Hand	Result
1. Magnetic field produced by current (RHR-1)		Wrap fingers around wire with thumb pointing in direction of current I	Fingers point in direction of $\vec{\mathbf{B}}$
2. Force on electric current I due to magnetic field (RHR-2)		Fingers point straight along current I, then bend along magnetic field $\vec{\mathbf{B}}$	Thumb points in direction of the force $\vec{\mathbf{F}}$
3. Force on electric charge $+q$ due to magnetic field (RHR-3)		Fingers point along particle's velocity $\vec{\mathbf{v}}$, then along $\vec{\mathbf{B}}$	Thumb points in direction of the force $\vec{\mathbf{F}}$

Example 10

- **What is the path of a charged particle in a uniform magnetic field if its velocity is *not* perpendicular to the magnetic field?**

- The velocity vector can be broken down into components parallel and perpendicular to the field.
- The velocity component parallel to the field lines experiences <u>*no force* </u>*(*θ = 0), so this component remains constant.
- The velocity component perpendicular to the field results in circular motion about the field lines.
- Putting these two motions together produces a helical (spiral) motion around the field lines as shown in Fig.



Thanks,..

See you next week (ISA),…