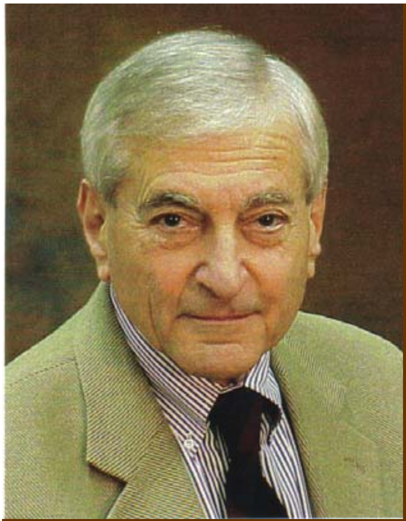
PHYS 1444 – Section 501
Lecture #14

Monday, Mar. 20, 2006
Dr. Jaehoon Yu

- Magnetism and Magnetic Field
- Electric Current and Magnetism
- Magnetic Forces on Electric Current
- About Magnetic Field
- Magnetic Forces on a Moving Charge
- Charged Particle Path in a Magnetic Field

Announcements

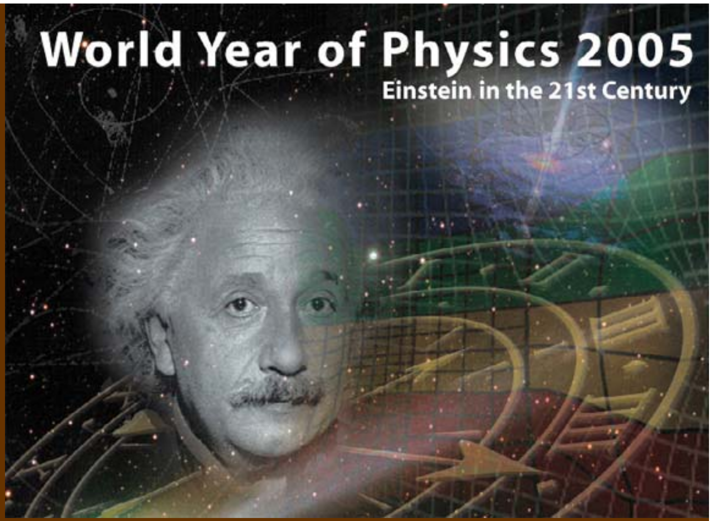
- Physics Department Colloquium
  - 4pm, Wednesday, Mar. 22
  - Dr. W. Rindler
  - Title: Cosmology from Einstein to Now
- Today's reading assignments
  - CH27 – 6 and 27 – 7
- Term exam #2
  - Date and time: 5:30 – 6:50pm, Wednesday, Apr. 5
  - Coverage: Ch. 25 – 4 to what we finish next Wednesday, Mar. 29. (Ch. 28?)



Cosmology from Einstein to now

Prof. Wolfgang Rindler
Director, Center for Theoretical Interdisciplinary Physics
Department of Physics
University of Texas at Dallas

4:00 pm Wed., March 22, SH Rm. 103



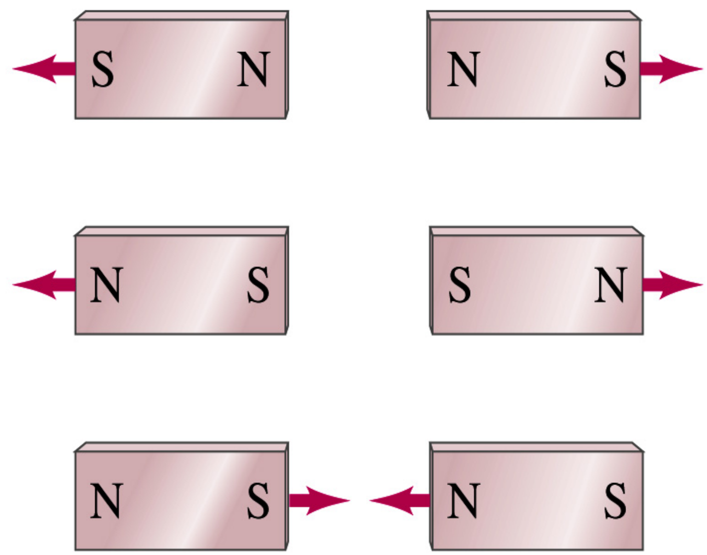
Abstract.

Modern cosmology begin in 1917 when Einstein published his now famous "Einstein Kosmos“. Then, the Mount Wilson 100-in telescope opened the window to the universe; theory and observation came together and true science flourished. The “big bang” goes a long way to explain cosmic discoveries. Progress has quickened in the last 25 years with the rise of inflationary theory, the rediscovery of Einstein's lambda term, cosmic acceleration, cosmic foam, dark matter, dark energy, along with the Hubble space telescope and the new 10-m Keck telescopes. Now, the universe seems essentially flat, infinite, 13.7 billion years old, and destined to expand forever. There are, however, hints of other universes.

Wolfgang Rindler born in Vienna was educated in England during World War II. His B.Sc. and M.Sc. are from Liverpool University and his Ph.D. is from Imperial College, London. He taught at Liverpool, London, and Cornell Universities, before joining the faculty at the then newly created Southwest Center for Advanced Studies in 1963, now the University of Texas at Dallas. Except for visiting professorships at the Universities of Rome and Vienna, and visiting fellowships at the University of Cambridge and the Max Planck Institutes at Munich and Potsdam, his home is UTD. He is the author or co-author of seven books (with translations into Russian, Japanese, Italian and Greek).

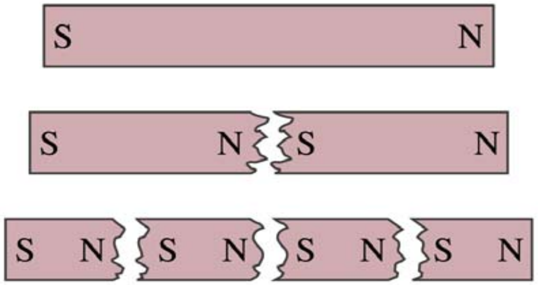
Magnetism

- What are magnets?
  - Objects with two poles, north and south poles
    - The pole that points to geographical north is the north pole and the other is the south pole
      - Principle of compass
  - These are called magnets due to the name of the region, Magnesia, where rocks that attract each other were found
- What happens when two magnets are brought to each other?
  - They exert force onto each other
  - What kind?
  - Both repulsive and attractive forces depending on the configurations
    - Like poles repel each other while the unlike poles attract



Magnetism

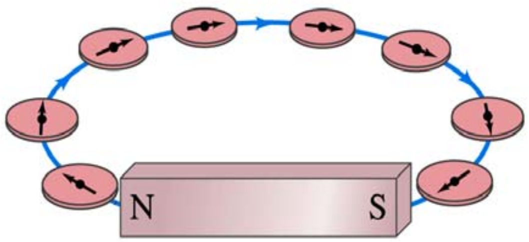
- So the magnet poles are the same as the electric charge?
  - No. Why not?
  - While the electric charges (positive and negative) can be isolated the magnet poles cannot be isolated.
  - So what happens when a magnet is cut?
    - If a magnet is cut, two magnets are made.
    - The more they get cut, the more magnets are made

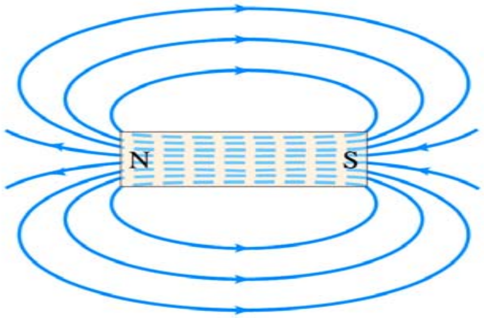


  - Single pole magnets are called the monopole but it has not been seen yet
- Ferromagnetic materials: Materials that show strong magnetic effects
  - Iron, cobalt, nickel, gadolinium and certain alloys
- Other materials show very weak magnetic effects

Magnetic Field

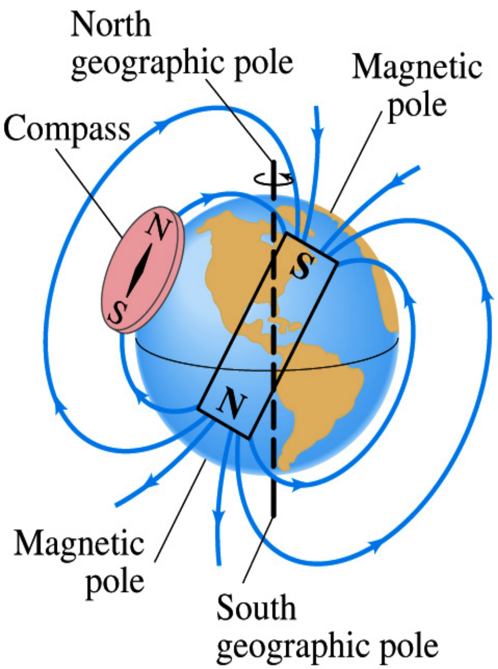
- Just like the electric field that surrounds electric charge, a magnetic field surrounds a magnet
- What does this mean?
  - Magnetic force is also a field force
  - The force one magnet exerts onto another can be viewed as the interaction between the magnet and the magnetic field produced by the other magnet
  - What kind of quantity is the magnetic field? Vector or Scalar? **Vector**
- So one can draw magnetic field lines, too.
  - The direction of the magnetic field is tangent to a line at any point
  - The direction of the field is the direction the north pole of a compass would point to
  - The number of lines per unit area is proportional to the strength of the magnetic field
  - Magnetic field lines continue inside the magnet
  - Since magnets always have both the poles, magnetic field lines form closed loops unlike electric field lines





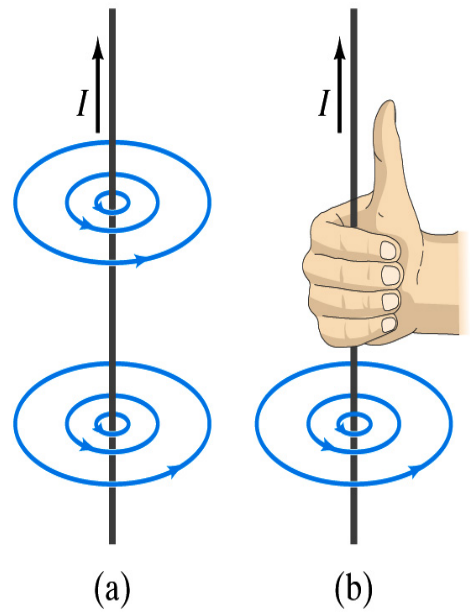
Earth's Magnetic Field

- What magnetic pole does the geographic north pole has to have?
  - Magnetic south pole. What? How do you know that?
  - Since the magnetic north pole points to the geographic north, the geographic north must have magnetic south pole
    - The pole in the north is still called geomagnetic north pole just because it is in the north
  - Similarly, south pole has magnetic north pole
- The Earth's magnetic poles do not coincide with the geographic poles ➔ magnetic declination
  - Geomagnetic north pole is in northern Canada, some 1300km off the true north pole
- Earth's magnetic field line is not tangent to the earth's surface at all points
  - The angle the Earth's field makes to the horizontal line is called the angle dip



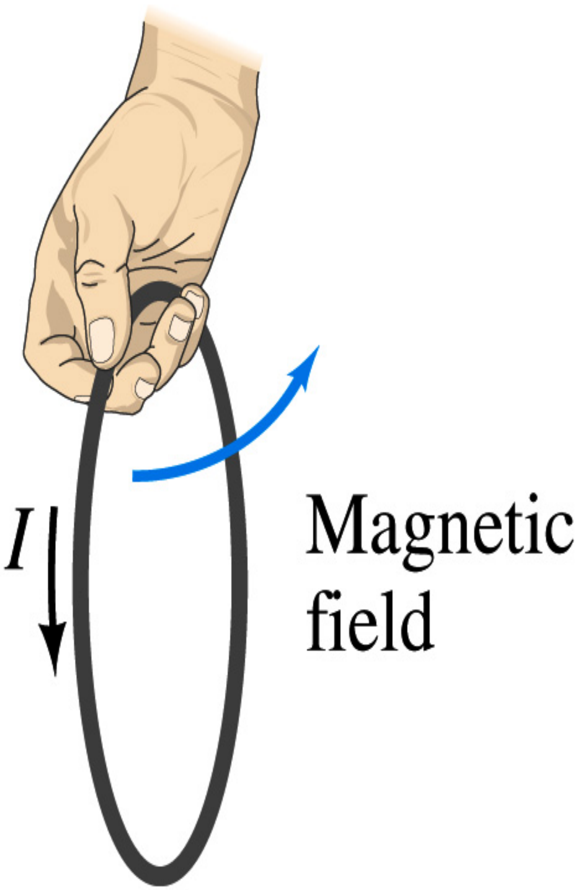
Electric Current and Magnetism

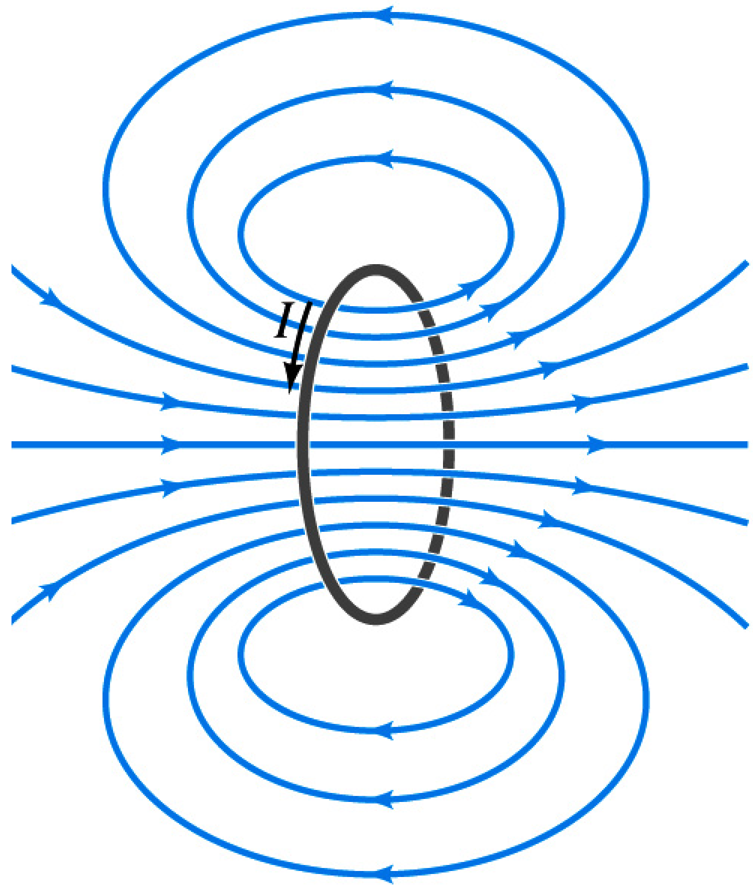
- In 1820, Oersted found that when a compass needle is placed near an electric wire, the needle deflects as soon as the wire is connected to a battery and the current flows
  - Electric current produces a magnetic field
    - The first indication that electricity and magnetism are the same thing
  - What about a stationary electric charge and magnet?
    - They don't affect each other.
- The magnetic field lines produced by a current in a straight wire is in the form of circles following the "right-hand" rule
  - The field lines follow right-hand's fingers wrapped around the wire when the thumb points to the direction of the electric current



Directions in a Circular Wire?

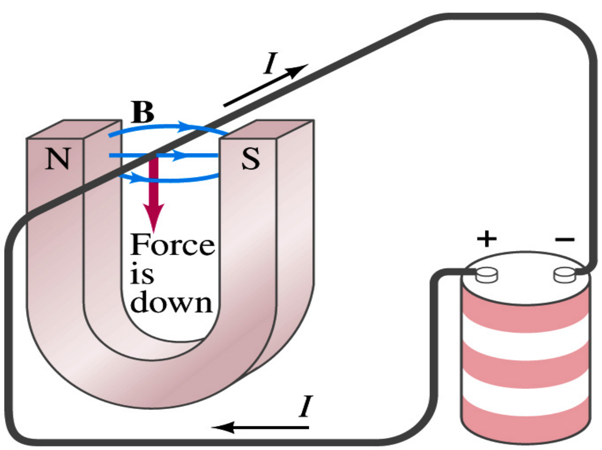
- OK, then what are the directions of the magnetic fields generated by the current flowing through circular loops?

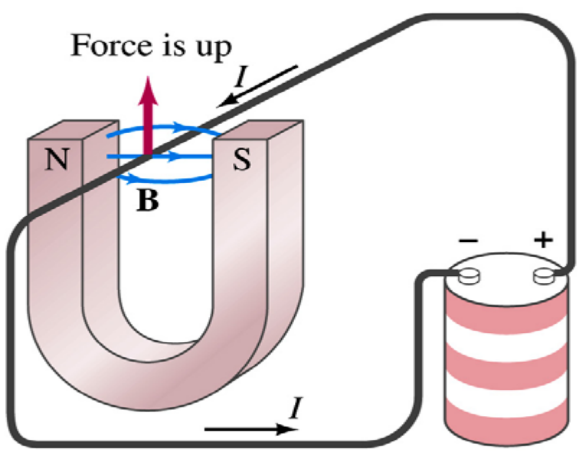


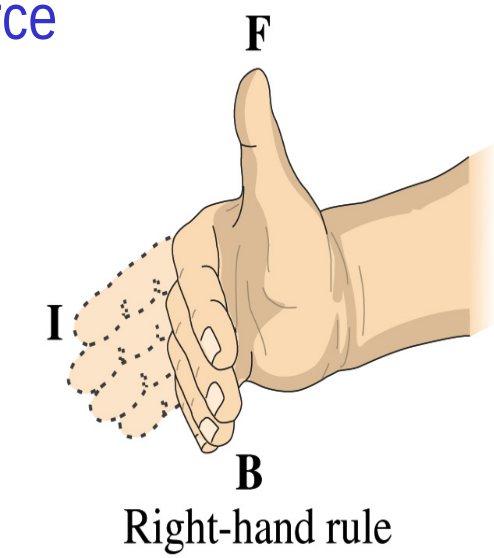


Magnetic Forces on Electric Current

- Since the electric current exerts force on a magnet, the magnet should also exert force on the electric current
  - Which law justifies this?
    - Newton's 3rd law
  - This was also discovered by Oersted
- Direction of the force is always
  - perpendicular to the direction of the current and also
  - perpendicular to the direction of the magnetic field, B
- Experimentally the direction of the force is given by another right-hand rule ➔ When the fingers of the right-hand points to the direction of the current and the finger tips bent to the direction of magnetic field B, the direction of thumb points to the direction of the force







Magnetic Forces on Electric Current

- OK, we are set for the direction but what about the magnitude?
- It is found that the magnitude of the force is directly proportional to
  - the current in the wire
  - The length of the wire in the magnetic field (if the field is uniform)
  - The strength of the magnetic field
- The force also depends on the angle θ between the directions of the current and the magnetic field
  - When the wire is perpendicular to the field, the force is the strongest
  - When the wire is parallel to the field, there is no force at all
- Thus the force on current I in the wire w/ length l in a uniform field $\mathcal{B}$ is

$$F \propto IlB\sin\theta$$

Magnetic Forces on Electric Current

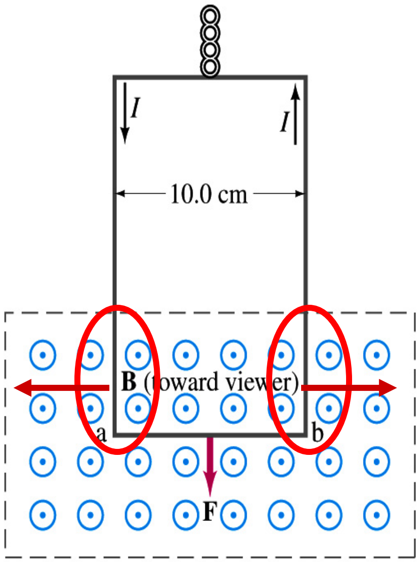
- Magnetic field strength B can be defined using the previous proportionality relationship w/ the constant 1: $F = IlB\sin\theta$
- if θ=90º, $F_{\max} = IlB$ and if θ=0º $F_{\min} = 0$
- So the magnitude of the magnetic field B can be defined as
  - $B = F_{\max} / Il$ where F_{max} is the magnitude of the force on a straight length ℓ of wire carrying a current I when the wire is perpendicular to B
- The relationship between F, B and I can be written in a vector formula: $\vec{F} = I\vec{l} \times \vec{B}$
  - ℓ is the vector whose magnitude is the length of the wire and its direction is along the wire in the direction of the conventional current
  - This formula works if B is uniform.
- If B is not uniform or ℓ does not form the same angle with B everywhere, the infinitesimal force acting on a differential length dℓ is $d\vec{F} = Id\vec{l} \times \vec{B}$

About the Magnetic Field, B

- The magnetic field is a vector quantity
- The SI unit for B is tesla (T)
  - What is the definition of 1 Tesla in terms of other known units?
  - 1T=1N/Am
  - In older names, tesla is the same as weber per meter-squared
    - $1Wb/m^2=1T$
- The cgs unit for B is gauss (G)
  - How many T is one G?
    - $1G=10^{-4}$ T
  - For computation, one MUST convert G to T at all times
- Magnetic field on the Earth's surface is about $0.5G=0.5\times10^{-4}T$
- On a diagram, $\odot$ for field coming out and $\otimes$ for going in.

Example 27 – 1

Measuring a magnetic field. A rectangular loop of wire hangs vertically as shown in the figure. A magnetic field B is directed horizontally perpendicular to the wire, and points out of the page. The magnetic field B is very nearly uniform along the horizontal portion of wire *ab* (length ℓ=10.0cm) which is near the center 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 force (in addition to the gravitational force) of F=3.48x10^{-2}N when the wire carries a current I=0.245A. What is the magnitude of the magnetic field B at the center of the magnet?



Magnetic force exerted on the wire due to the uniform field is $\vec{F} = I\vec{l} \times \vec{B}$

Since $\vec{B} \perp \vec{l}$ Magnitude of the force is $F = IlB$

Solving for B

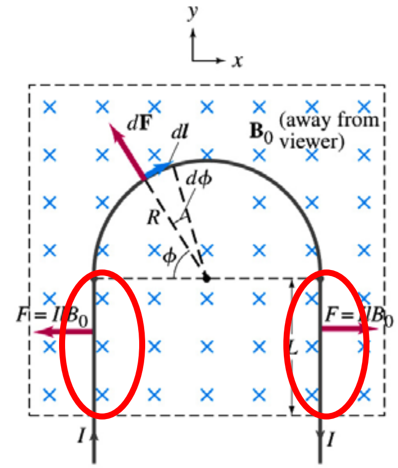
$$B = \frac{F}{Il} = \frac{3.48 \times 10^{-2}\,N}{0.245A \cdot 0.10m} = 1.42T$$

Something is not right! What happened to the forces on the loop on the side?

The two forces cancel out since they are in opposite direction with the same magnitude.

Example 27 – 2

Magnetic force on a semi-circular wire. A rigid wire, carrying the current I, consists of a semicircle of radius R and two straight portions as shown in the figure. The wire lies in a plane perpendicular to the uniform magnetic field B_0. The straight portions each have length ℓ within the field. Determine the net force on the wire due to the magnetic field B_0.



As in the previous example, the forces on the straight sections of the wire is equal and opposite direction. Thus they cancel.

What do we use to figure out the net force on the semicircle? $d\vec{F} = Id\vec{l} \times \vec{B}$

We divide the semicircle into infinitesimal straight sections. $dl = Rd\phi$

What is the net x component of the force exerting on the circular section? **0** Why?

Because the forces on left and the right-hand sides of the semicircle balance.

Since $\vec{B}_0 \perp d\vec{l}$ Y-component of the force dF is $dF = d\left(F\sin\phi\right) = IRB_0 d\phi$

Integrating over ϕ=0→π

$$F = \int_0^{\pi} d\left(F\sin\phi\right) = IB_0R\int_0^{\pi}\sin\phi d\phi = -IB_0R\left[\cos\phi\right]_0^{\pi} = 2RIB_0$$

Which direction?

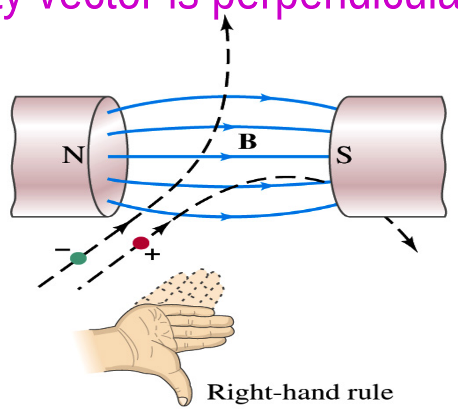
Vertically upward direction. The wire will be pulled deeper into the field.

Magnetic Forces on a Moving Charge

- Will moving charge in a magnetic field experience force?
  - Yes
  - Why?
  - Since the wire carrying a current (moving charge) experience force in a magnetic field, a free moving charge must feel the same kind of force…☺
- OK, then how much force would it experience?
  - Let's consider N moving particles with charge q each, and they pass by a given point in time interval t.
    - What is the current? $I = Nq/t$
  - Let t be the time for a charge q to travel a distance L in a magnetic field B
    - Then, the length vector ℓ becomes $\vec{l} = \vec{v}t$
    - Where v is the velocity of the particle
- Thus the force on N particles by the field is $\vec{F} = I\vec{l} \times \vec{B} = Nq\vec{v} \times \vec{B}$
- The force on one particle with charge q, $\vec{F} = q\vec{v} \times \vec{B}$

Magnetic Forces on a Moving Charge

- This can be an alternative way of defining the magnetic field.
  - How?
  - The magnitude of the force on a particle with charge q moving with a velocity v in the field is
    - $F = qvB\sin\theta$
    - What is θ?
      - The angle between the magnetic field and the direction of particle's movement
    - When is the force maximum?
      - When the angle between the field and the velocity vector is perpendicular.
    - $F_{max} = qvB$ ➔ $B = \frac{F_{max}}{qv}$
  - The direction of the force follows the right-hand-rule and is perpendicular to the direction of the magnetic field



Example 27 – 3

Magnetic force on a proton. A proton having a speed of 5×10^6 m/s in a magnetic field feels a force of $F=8.0\times10^{-14}$ 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?

What is the charge of a proton? $q_p = +e = 1.6\times10^{-19}C$

What does the fact that the proton does not feel any force in a northerly direction tell you about the magnetic field?

The field is along the north-south direction. Why?

Because the particle does not feel any magnetic force when it is moving along the direction of the field.

Since the particle feels force toward the west, the field should be pointing to …. North

Using the formula for the magnitude of the field B, we obtain

$$B = \frac{F}{qv} = \frac{8.0\times10^{-14}N}{1.6\times10^{-19}C\cdot 5.0\times10^{6}m/s} = 0.10T$$

We can use magnetic field to measure the momentum of a particle. How?