PHYS 1441 – Section 002
Lecture #16

Monday, Nov. 5, 2018

Dr. Jaehoon Yu

- Chapter 27: Magnetism & Magnetic Field
  - Electric Current and Magnetism
  - Magnetic Field
  - Magnetic Force on a Moving Charge
  - About Magnetic Field
  - Charged Particle Path in a Magnetic Field

Today's homework is homework #11, due 11pm, Monday, Nov. 19!!

Announcements

- Reminder:2nd non-comprehensive term exam
  - In class Wednesday, Nov. 14
  - Covers CH25.5 to what we learn Monday, Nov. 12
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants
  - No derivations, word definitions or solutions of any kind!
  - No additional formulae or values of constants will be provided

Reminder: Special Extra Credit #4

- **Election Participation Exercise**
- For those with legal voting rights: You can submit three "I Voted" stickers or the access code green sheet for 20 points total – one your own and two others who voted and the remainder 2 points each
- For those without legal voting rights: You can submit for the first four "I Voted" sticker or the access code green sheet for 20 points total and the remainder 2 points each
- Be sure to tape one side of the stickers on a sheet of paper with your name on it.
  - Write the precinct number the vote was cast, the full name of the person voted and the signature of the voter next to the relevant sticker
- None of the stickers can be from the same person on someone else's extra credit or on your own. All of those with any of the identical persons on your extra credit sheet will get 0 credit.
- Deadline: Beginning of the class this Wednesday, Nov. 7

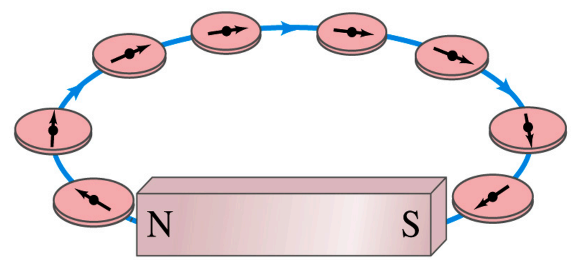
Special Project #5

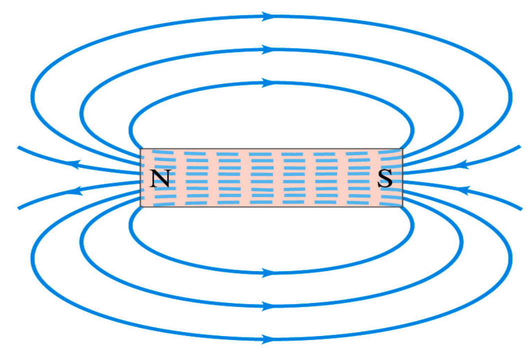
- Make a list of the power consumption and the resistance of all electric and electronic devices at your home and compile them in a table. (10 points total for the first 10 items and 0.5 points each additional item.)
- Estimate the cost of electricity for each of the items on the table using your own electric cost per kWh (if you don't find your own, use $0.12/kWh) and put them in the relevant column. (5 points total for the first 10 items and 0.2 points each additional items)
- Estimate the the total amount of energy in Joules and the total electricity cost per day, per month and per year for your home. (8 points)
- Due: Beginning of the class Wednesday, Dec. 5

Item Name	Rated power (W)	Num ber of device s	Number of Hours per day	Daily Power Consump tion (kWh)	Energy Cost per kWh (cents)	Daily Energy Consum ption (J).	Daily Energy Cost ($)	Monthl y Energy Consum ption (J)	Monthl y Energy Cost (S)	Yearly Energy Consum ption (J)	Yearly Energy Cost ($)
Light Bulbs	30	4									
	40	6									
	60	15									
Heaters	1000	2									
	1500	1									
	2000	1									
Home Appliances (Fans, vacuum cleaners, hair dryers, pool pumps, etc)											
Air Conditioners											
Kitchen Appliances (Fridges, freeezers, cook tops, microwave ovens,											
Computing devices (desktop, laptop, ipad, mobile phones, printers, chargers, etc))											
Tools (power tools, electric mower, electric cutter, etc)											
Medical Devices (blood pressure machine, thermometer, etc)											
Total				0		0	0	0	0	0	0

Magnetic Field

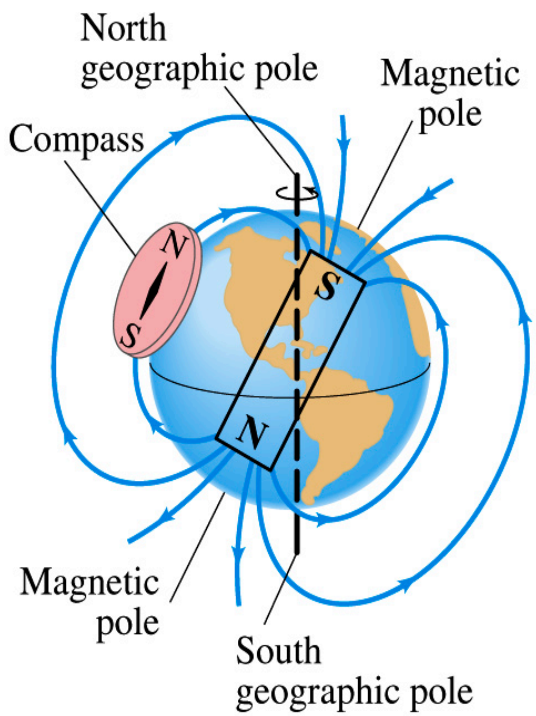
- Just like the electric field that surrounds electric charge, the magnetic field surrounds a magnet
- What does this mean?
  - Magnetic force is also a field force
  - The force one magnet exerts onto another can be viewed as the interaction between the magnet and the magnetic field produced by the other magnets
  - 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 tangential to the 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





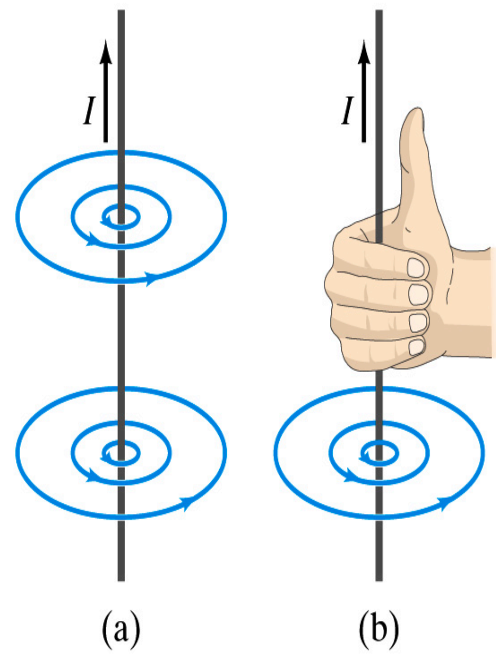
Earth's Magnetic Field

- 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 900km 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



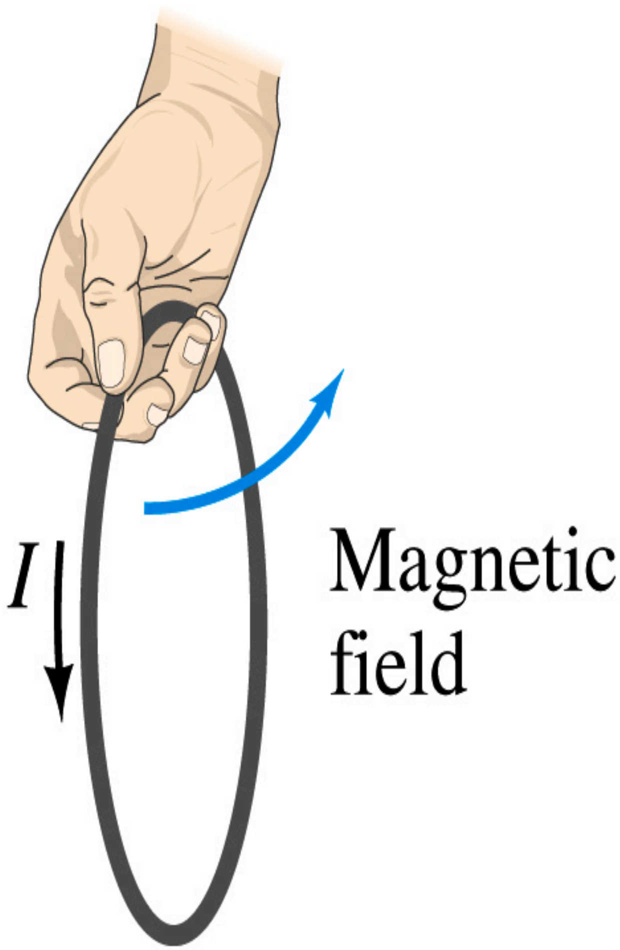
Electric Current and Magnetism

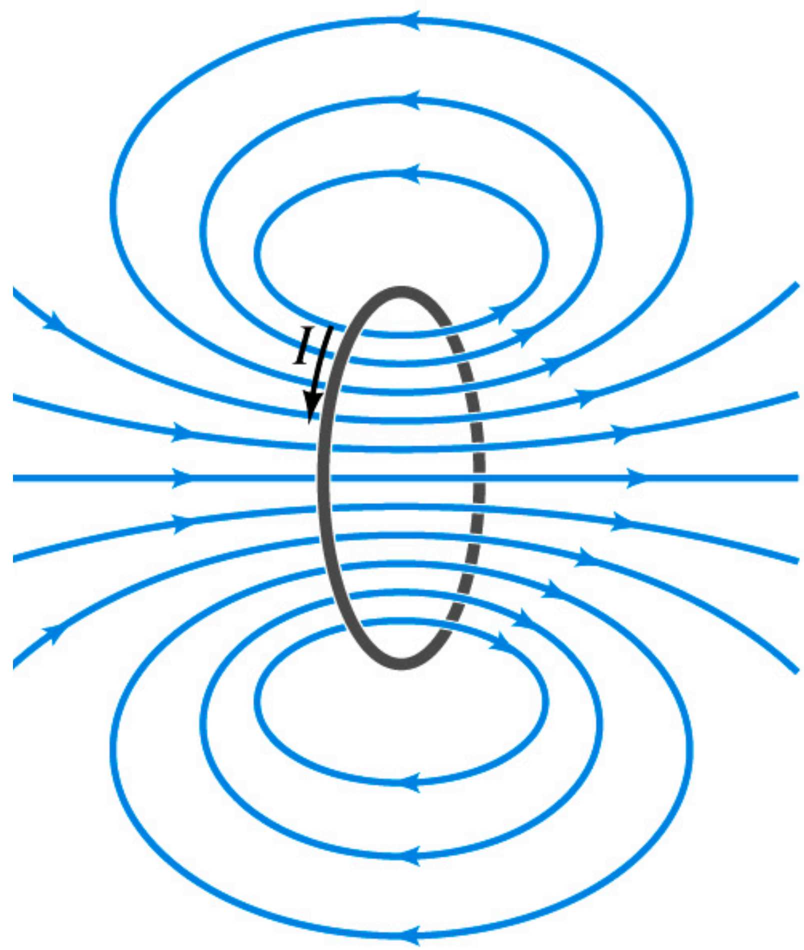
- In 1820, Oersted found that when a compass needle is placed near an electric wire, the needle deflects as soon as the wire is connected to a battery and the current flows
  - Electric current produces a magnetic field
    - The first indication that electricity and magnetism are of the same origin
  - 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 fingers wrapped around the wire when the thumb points to the direction of the electric current



Directions in a Circular Wire?

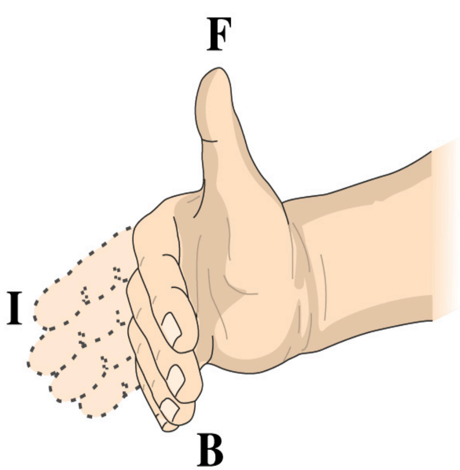
- OK, then what is the direction of the magnetic field generated by the current flowing through a circular loop?



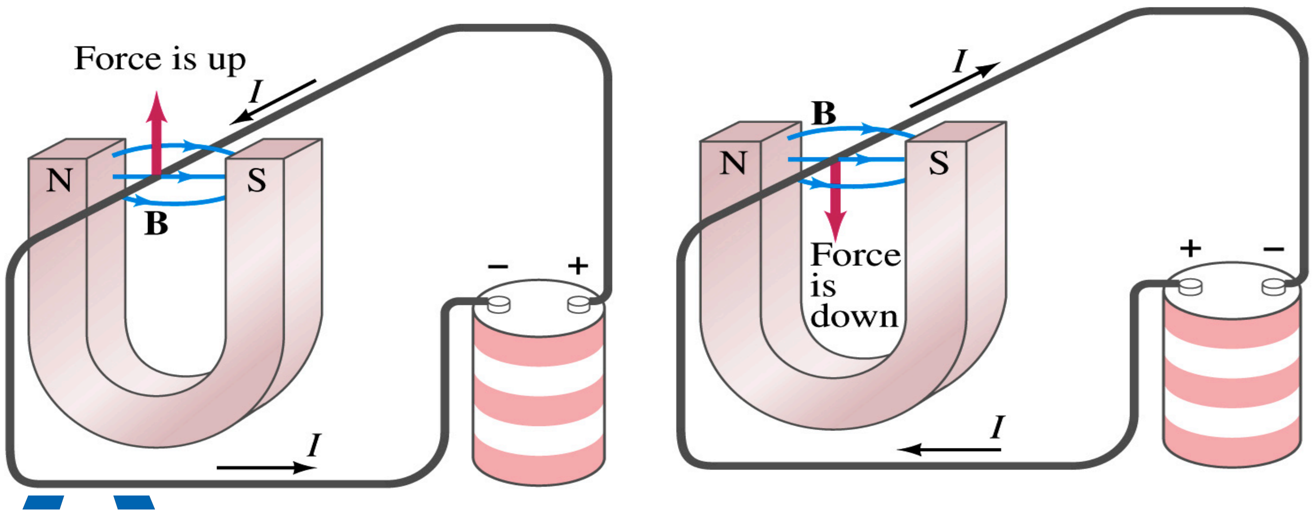


Magnetic Forces on Electric Current

- 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
  - 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



Right-hand rule



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
  - To the length of the wire in the magnetic field (if the field is uniform)
  - To 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

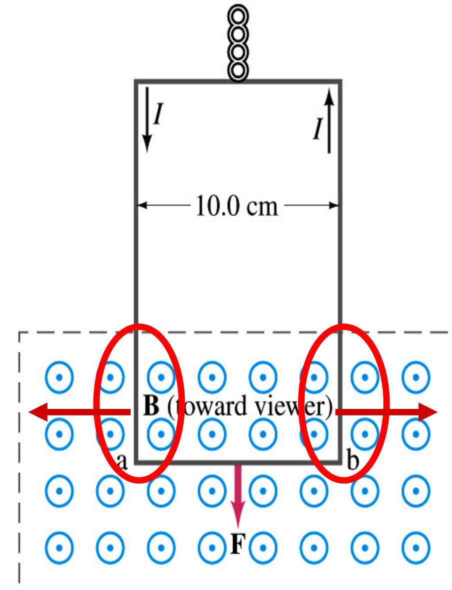
- Magnetic field strength B can be defined using the previous proportionality relationship w/ the constant 1: $F = IlB\sin\theta$
- if θ=90°, $F_{max} = IlB$ and if θ=0° $F_{min} = 0$
- So the magnitude of the magnetic field B can be defined as
  - $B = F_{max}/Il$ where F_{max} is the magnitude of the force on a straight length l of the wire carrying the 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 $d\vec{F} = Id\vec{l} \times \vec{B}$

Fundamentals on 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/A-m
  - 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 – 2

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 $F = IlB$

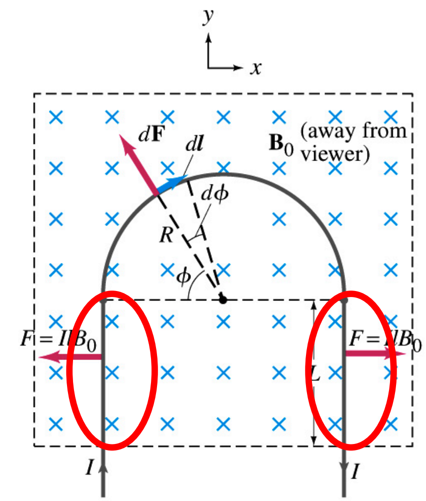
Solving for B $B = \frac{F}{Il} = \frac{3.48 \times 10^{-2}\,N}{0.245A \cdot 0.10m} = 1.42T$

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 – 3

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 $\mathbf{B_0}$. The straight portions each have length ℓ within the field. Determine the net force on the wire due to the magnetic field $\mathbf{B_0}$.



As in the previous example, the forces on the straight sections of the wire is equal and in 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 $dF_y = d\left(F\sin\phi\right) = IRB_0 d\phi$

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.