Homework due tonight 11:59 PM
Office hour today after class (3-4PM) in Serin 287 2nd floor tea room

SUNDAY Nov 18: SECOND HOUR EXAM 6:10-7:30 PM in SEC 111 (Ch. 26-30) -- no recitations the previous Friday and following Monday
Chapter 29

Magnetic Field and Forces
A DIFFERENT TYPE OF FORCE

Two metal bars attract
If one is flipped over, they repel
A DIFFERENT TYPE OF FORCE

Two metal bars attract
If one is flipped over, they repel

NOT GRAVITY – ALWAYS ATTRACTIVE
A DIFFERENT TYPE OF FORCE

Two metal bars attract
If one is flipped over, they repel

NOT ELECTRIC – ELECTRIC FIELD IS ZERO
Associated with certain materials:
Earliest known is LODESTONE

Alignment of lodestone needles:
Force comes from nearby lodestone

Lodestone needles align N-S in the absence of a nearby lodestone
COMPASS (Earth = lodestone)
Magnetism as a mysterious “lodestone” force: Lodestones exert forces on other lodestones Known for thousands of years
Force is exerted by lodestone / bar magnet ON MOVING CHARGES

DEMO: wire with electric current in a magnet

No magnet + no current = no force
Force is exerted by lodestone / bar magnet ON MOVING CHARGES

DEMO: wire with electric current in a magnet

No magnet + CURRENT = no force
Force is exerted by lodestone / bar magnet ON MOVING CHARGES

DEMO: wire with electric current in a magnet

U-magnet + no current = no force
Force is exerted by lodestone / bar magnet ON MOVING CHARGES

DEMO: wire with electric current in a magnet

U-magnet + no current = no force
Force is exerted by lodestone / bar magnet ON MOVING CHARGES

DEMO: wire with electric current in a magnet

Magnet + current = upward force!
Reverse current?
Force is exerted by lodestone/bar magnet ON MOVING CHARGES

DEMO: wire with electric current in a magnet

Turn on current = upward force
Reverse current -> downward force
Force is exerted by lodestone or bar magnet ON MOVING CHARGES

DEMO: cathode ray tube
Beam of electrons from back of device hits the screen and makes it glow
Bar magnet deflects the beam
Charged objects exert forces by creating a vector field called the electric field $\vec{E}(\vec{r})$ producing a force $\vec{F} = q\vec{E}(\vec{r})$.

Lodestone and bar magnets exert forces by creating a vector field called the magnetic field $\vec{B}(\vec{r})$.

Bar magnet field: [Diagram showing S and N poles]
(near ends)

**Today:** start with a given magnetic field and find the magnetic force on moving electric charges

**Next week:** learn about currents inside atoms in lodestones

Magnetic force on the lodestone
the magnetic field is produced by currents (lodestones, wires)
The magnetic force on a charged particle in a magnetic field \( \vec{B}(\vec{r}) \)

**Magnitude:**
Proportional to magnitude of \( B \) at \( \vec{r} \)
Proportional to magnitude of charge \( |q| \)
Proportional to speed \( v \) -> zero force if not moving
Depends on angle between \( \vec{v} \) and \( \vec{B} \)
zero if \( \vec{v} \) and \( \vec{B} \) are parallel or antiparallel)

Magnitude = \(|q| \ v \ B \ \sin \phi\)
Units of \( B \): 1 N/(C m/s) = 1 T (Tesla)
The magnetic force on a charged particle in a magnetic field $\vec{B}(\vec{r})$

Magnitude: $|q| v B \sin \phi$

**Direction:**
Perpendicular to direction of $\vec{v}$
Perpendicular to direction of $\vec{B}$
$\to$ normal to the plane defined by $\vec{v}$ and $\vec{B}$

Two choices – use right-hand rule to choose
Thumb along $\vec{v}$; fingers along $\vec{B}$: **out of palm**

To put it all together:

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

Cross product of two vectors
i-clicker:
An proton is traveling in the positive x direction. It enters a magnetic field pointing in the positive z direction. In which direction is the force on the proton?

a) +x
b) -x
c) -y
d) +y
e) +z
i-clicker:
An proton is traveling in the positive x direction. It enters a magnetic field pointing in the positive z direction. In which direction is the force on the proton?

a) +x
b) -x
c) -y
d) +y
e) +z
i-clicker:
An electron is traveling in the positive z direction. It enters a magnetic field pointing in the positive x direction. In which direction is the force on the electron?

a) +x
b) -x
c) -y
d) +y
e) -z
i-clicker:
An electron is traveling in the positive z direction. It enters a magnetic field pointing in the positive x direction. In which direction is the force on the electron?

a) +x  
b) -x  
c) -y  
d) +y  
e) -z

Check with the demo!
i-clicker:
An electron is traveling in the positive z direction. It enters a magnetic field pointing in the positive x direction. In which direction is the force on the electron?

a) +x  
b) -x  
c) -y  
d) +y  
e) -z
Motion of a charged particle $q$ in a uniform field $B$ $v_0$ along a field line
Motion of a charged particle $q$ in a uniform field $B$ $v_0$ perpendicular to the field
Motion of a charged particle $q$ in a uniform field $B$ $v_0$ perpendicular to the field

$F = q \, v_0 \, B$ out of the screen

**perpendicular to the displacement**

$B$ field does no work on the particle does not change its speed
Motion of a charged particle $q$ in a uniform field $B$ parallel to the field.

Initially $F = q \, v_0 \, B$ downward.

$B$ out of the screen.
Motion of a charged particle $q$ in a uniform field $B$ \( v_0 \) perpendicular to the field

$B$ out of the screen

Initially $F = q \, v_0 \, B$ downward
Motion of a charged particle $q$ in a uniform field $B$ $v_0$ perpendicular to the field

Speed is constant (why?)
Force is perpendicular to motion, constant magnitude
Uniform circular motion
Radius of the circle: $qv_0B = mv_0^2/r$ so $r = mv_0/qB$

DEMO: in bulb, vary the B field to change the radius
Motion of a charged particle $q$ in a uniform field $B$
$v_{0x}$ perpendicular to the field
$v_{0z}$ parallel to the field

B out of the screen

helix
Velocity Selector

Motion of a charged particle in crossed E and B field

B out of the screen
E upward

Magnetic force downward
electric force upward
If $E = vB$, net force is zero and particle will not change velocity