Physics 202, Lecture 11

Today's Topics

- Exam 1 Result
- Magnetic Fields and Forces (Ch. 29)
  - Magnetic materials
  - Magnetic forces on moving point charges
  - Magnetic forces on currents, current loops
  - Motion of charge in uniform B field

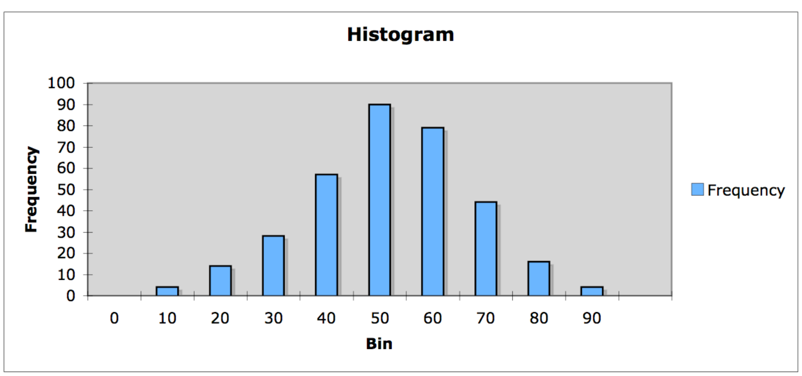
Thurs: applications (cyclotron, velocity selector, Hall effect)

Homework #5: due 10/15 ,10 PM

Optional reading quiz: due 10/12, 5 PM

Exam 1 Results

Median: 57 Average: 57.3 Std dev: 15.3



Grade ranges (approx):

75-96 A 68-74 AB 57-67 B 48-56 BC 37-47 C <37 D

Magnetism: Overview

- Previously: electrostatics
  - Forces and fields due to stationary charges
  - Coulomb force F_E, Electrostatic field E:

$$\vec{F}_E = q\vec{E}$$

- Now: magnetism
  (historically: magnetic materials, Oersted effect)
  - Forces and field due to moving charges (currents)
  - Magnetic Force F_B, magnetic field B:

$$\vec{F}_B = qv \times \vec{B} \quad \text{(charges: Lorentz force)}$$

$$\vec{F}_B = \int I d\vec{l} \times \vec{B} \quad \text{(currents: Biot-Savart law)}$$

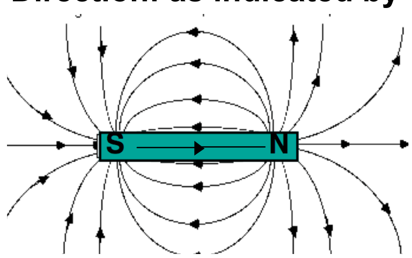
Magnetic Materials (1)

Focus first on bar magnets (permanent magnets):
Two types of poles: N and S

Magnetic forces: like poles repel, opposite poles attract

Magnetic field: B (vector field).
Units: 1 Tesla (T) = 1 N/(A m)

Direction: as indicated by compass's "north" pole



Field lines:
Outside magnet: N to S
Inside magnet: S to N

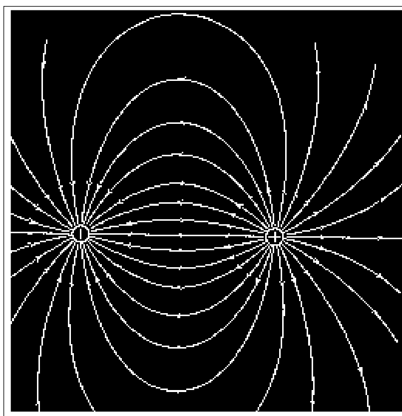
Typical Magnetic Field Strengths

Table 29.1

Some Approximate Magnetic Field Magnitudes

Source of Field	Field Magnitude (T)
Strong superconducting laboratory magnet	30
Strong conventional laboratory magnet	2
Medical MRI unit	1.5
Bar magnet	10^{-2}
Surface of the Sun	10^{-2}
Surface of the Earth	0.5×10^{-4}
Inside human brain (due to nerve impulses)	10^{-13}

1 Gauss = 10^{-4} Tesla

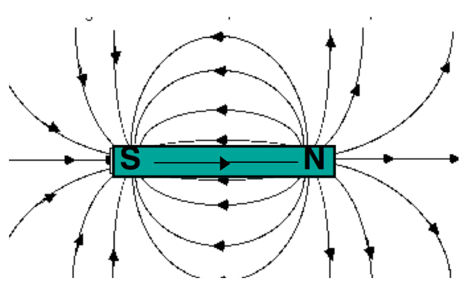


Electrostatics analogy:

Electric Field Lines of an Electric Dipole

dipole field!

Magnetic Field Lines of a bar magnet



Magnetic Monopoles

- ❑ Perhaps there exist magnetic charges, just like electric charges: magnetic monopole (+ or - magnetic charge).
- ❑ How can you isolate this magnetic charge?

Try cutting a bar magnet in half:

Even an individual electron has a magnetic "dipole"!

Despite extensive searches,
magnetic monopoles have never been found!

$$\oint \vec{B} \bullet d\vec{A} = 0$$ (compare Gauss's Law)

Bar Magnets and Compass

Recap: 2 magnetic poles, N and S

- like poles repel, opposite poles attract
- both poles attract iron (ferromagnetic material)
- Two poles not separable

Compass: a bar magnet

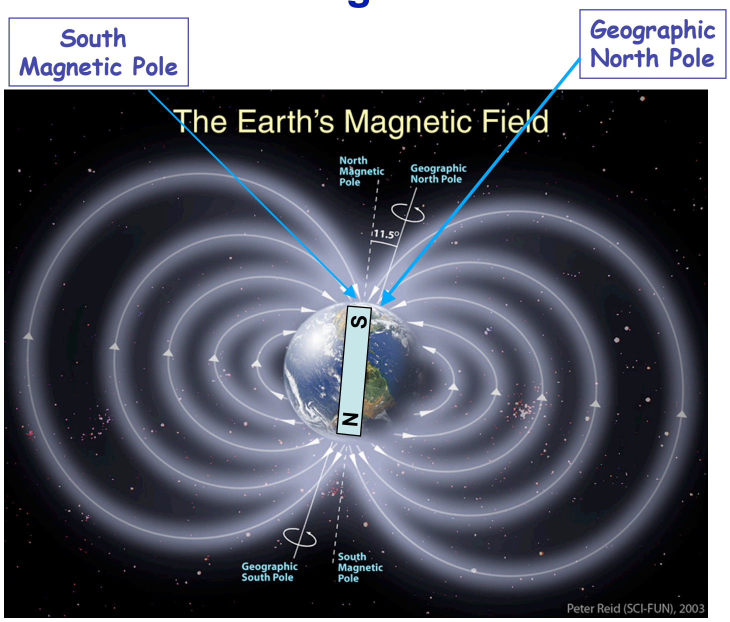
- Its "north" pole (conventionally defined) points towards the northern direction

Magnets

Modern compasses

An ancient Chinese compass (~220BC)

Earth's Magnetic Field

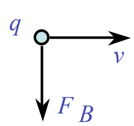


Magnetic Force

We know about the existence of magnetic fields by the force they exert on moving charges.

- ❑ **What is the "magnetic force"?**
  How is it distinguished from the "electric" force?

Experimental observations about the magnetic force F_B:



a) magnitude: $\propto$ to velocity of q

b) direction: $\perp$ to direction of q's velocity

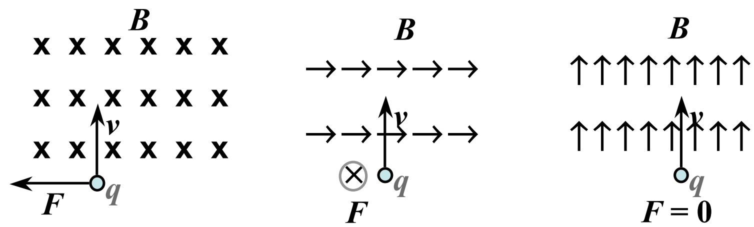
c) direction: $\perp$ to direction of B

B is the magnetic field vector

Magnetic Force

Force F on charge q moving with velocity v through region of space with magnetic field **B**:

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

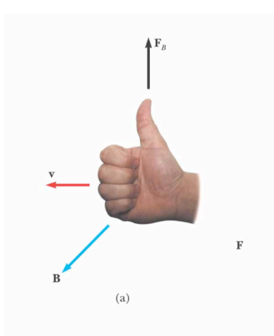


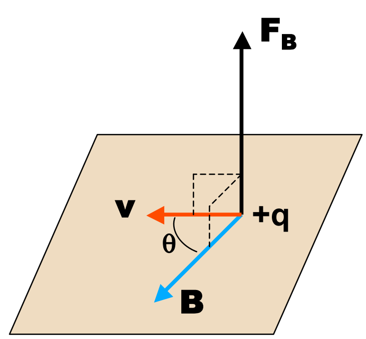
If also electric field **E**: **Lorentz Force Law**

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

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

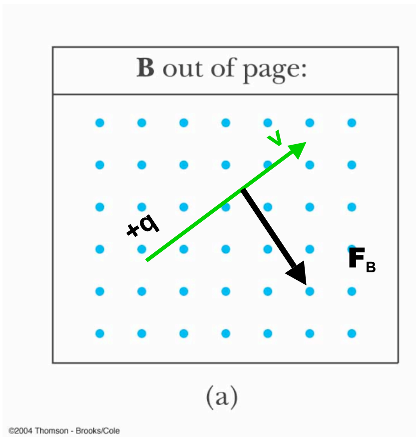
- Cross product review (board; see also text Ch 11.1):
  - direction: "right hand rule"
  - magnitude: $F = qvB\sin\theta$

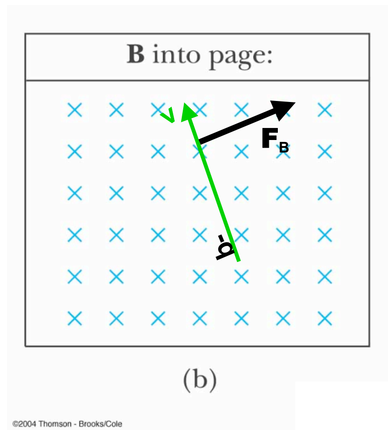




Exercise: Direction of Magnetic Force

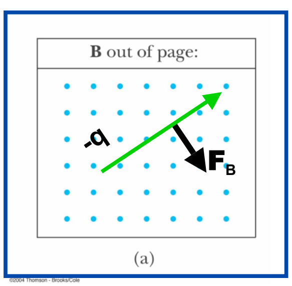
- ❑ Indicate the direction of $\mathbf{F}_B$ in the following situations:

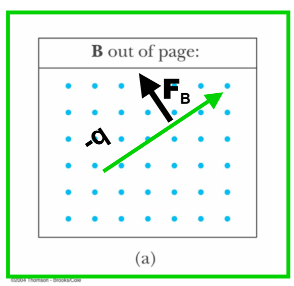


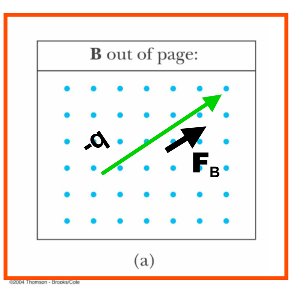


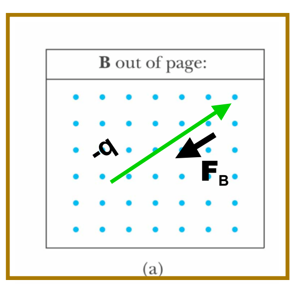
Question 1 : Direction of Magnetic Force

- ❑ Which fig has the correct direction of $\mathbf{F}_B$?



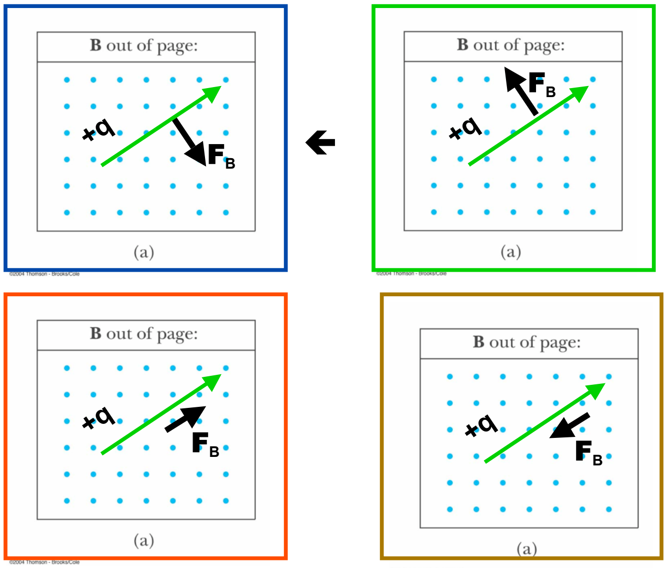






Question 2 : Direction of Magnetic Force

- Which fig has the correct direction of $\mathbf{F}_B$?

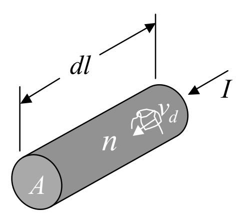


Magnetic Force On Current Carrying Wire(1)

Now you know how a single charged particle moves in a magnetic field. What about a group?

In a portion of current-carrying conducting wire:

n	number of charges per unit volume
A	area of the conductor
dl	length of the element
$\vec{v}_d$	drift velocity of a charge



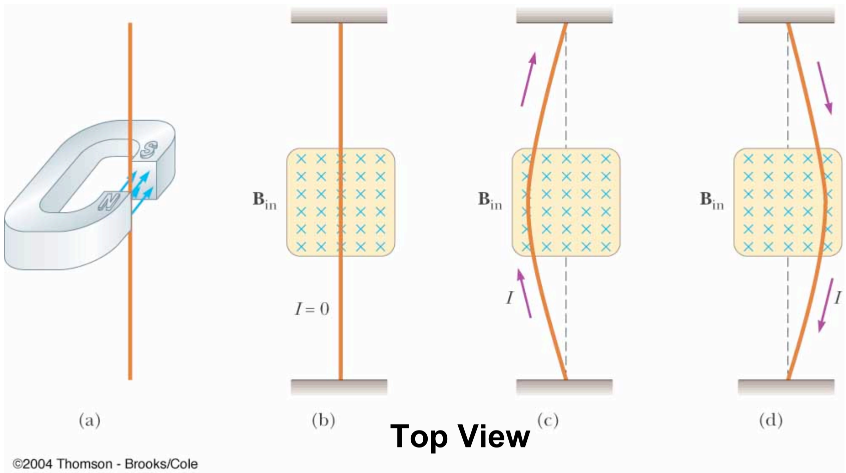
then

$$\vec{F}_B = nAdl\left(q\vec{v}_d \times \vec{B}\right) = I\,d\vec{l} \times \vec{B}$$

$$\Rightarrow I\int d\vec{l} \times \vec{B} = I\vec{L} \times \vec{B}$$

(for uniform field)

Magnetic Force On A Current Carrying Wire (2)



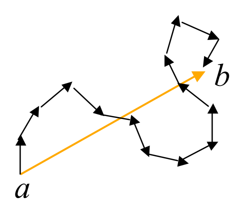
Also: bending electron beam

Magnetic Force On Current Carrying Wire(3)

For a uniform magnetic field:

To get the sum of a number of vectors - put them all head to tail and connect the initial (*a*) and final point (*b*):

$$\int_a^b d\vec{l} = \vec{L}_{ba}$$

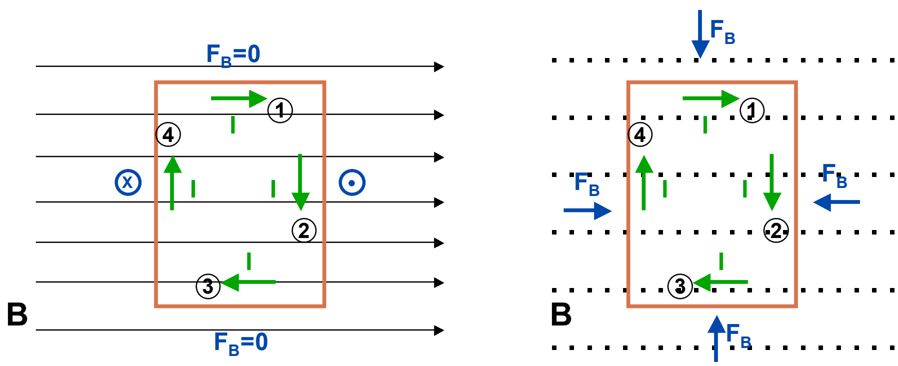


If the initial and final points are the same, the integral is zero!

There is no net magnetic force on a closed current loop in a uniform magnetic field.

Forces on a Current Loop

For current loops in a uniform magnetic field as shown, what is the direction of the force on each side?



Case 1

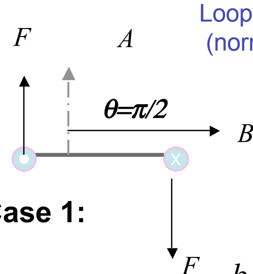
recall: $\Sigma \mathbf{F}_B = 0$

Case 2

Torque on Current Loop in Uniform B Field

Though the net magnetic force on a closed current loop in a uniform B field is zero, there can be a net torque.

Loop has length dimension *a* (normal to ***B***), width *b*.

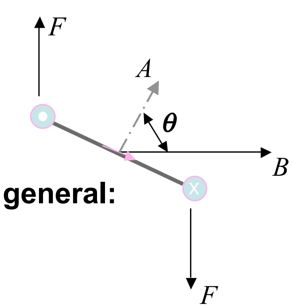


Case 1:

$$\tau = 2F\frac{b}{2}\sin\theta = IabB\sin\theta$$

$$\vec{\tau} = I\vec{A}\times\vec{B}$$

More general:



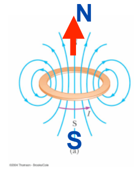
Define the magnetic moment $\vec{\mu} \equiv I\vec{A}$

$$\vec{\tau} = \vec{\mu}\times\vec{B}$$

$\vec{\mu} = NI\vec{A}$ **(N turns)**

Magnetic Dipole Moments

- ❑ Magnetic dipole moment μ.

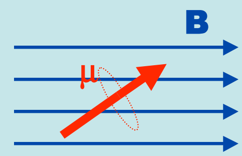


Macroscopic
$\mu = I\mathbf{A}$

Microscopic
$\mu \propto \mathbf{L}$

angular momentum of orbiting or spin

definition of magnetic moment

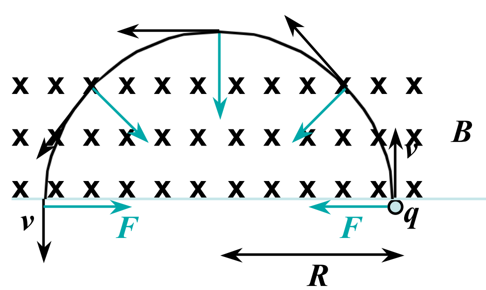


$$\sum F = 0$$
$$\vec{\tau} = \vec{\mu} \times B$$
$$U = -\vec{\mu} \bullet B$$

μ in B Field

Trajectory in Constant B Field (1)

- Suppose charge q enters a uniform B-field with velocity v. What will be the path that q follows?



Force perpendicular to velocity: uniform circular motion

Note: magnetic force does no work on the charge!
Kinetic energy constant

Trajectory in Constant B Field (2)

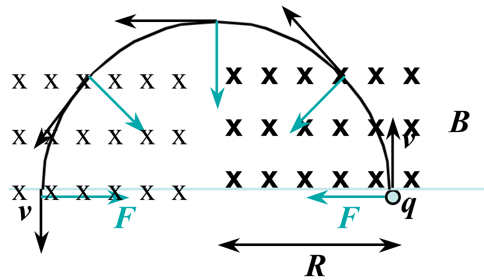
- **Force:**

$$F = qvB$$

- **centripetal acc:**

$$a = \frac{v^2}{R}$$

- **Newton's 2nd Law:**



$$F = ma \quad \Rightarrow \quad qvB = m\frac{v^2}{R}$$

$$\Rightarrow \quad R = \frac{mv}{qB} = \frac{p}{qB}$$

"Cyclotron" frequency:

$$\omega = \frac{v}{R} = \frac{qB}{m}$$