PHY132H1F Introduction to Physics II
Class 20 – **Outline:**

- Finishing Ch.33:
- Magnetic Forces with current carrying wires
- The Mass Spectrometer
- Ch. 35 Sections 1-4:
- Relating Electric and Magnetic Fields
- Maxwell's Equations
- The speed of light

Quick Ch. 35 reading quiz..

Galilean Relativity compares *inertial* reference frames where relative speeds are much less than c. The principle of relativity states that

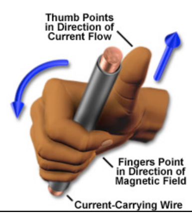
A. Velocity, acceleration, and force are all relative, meaning: *they depend on the reference frame of the observer.*
B. Velocity is relative, but acceleration and force *do not* depend on the reference frame of the observer.
C. Velocity and acceleration are relative, but force *does not* depend on the reference frame of the observer.
D. Velocity and force are relative, but acceleration *does not* depend on the reference frame of the observer.
E. Acceleration and force are relative, but velocity *does not* depend on the reference frame of the observer.

In Class Discussion Question: review of Ch.33

(using Right Hand Rule for Fields)

An electric power line carries a steady current of 150 A toward the North. At a point in space 5 m above the wire, what is the direction of the magnetic field due to the current in the wire?

A. North
B. South
C. East
D. West
E. Up or Down

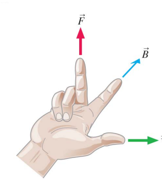


In Class Discussion Question: review of Ch.33

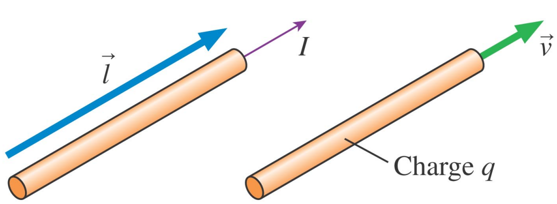
(using Right Hand Rule for Fields, and Right Hand Rule for Forces)

An electric power line carries a steady current of 150 A toward the North. A negatively charged rain-drop (q = –1 nC) is falling directly above the wire at its terminal velocity of 3 m/s, downward. When the drop is a distance of 5 m above the wire, what is the direction of the magnetic force on the drop due to the current in the wire?

A. North
B. South
C. East
D. West
E. Up or Down



Two ways to think of a current:



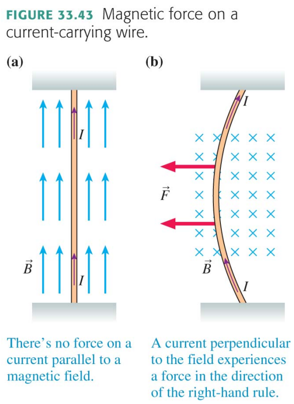
A current consists of charge carriers q moving with velocity $\vec{v}$.

Magnetic Forces on Current-Carrying Wires

Consider a segment of wire of length l carrying current I in the direction of the vector $\boldsymbol{l}$. The wire exists in a constant magnetic field $\boldsymbol{B}$. The magnetic force on the wire is

$$F_{\text{wire}} = Il \times B = (IlB\sin\alpha, \text{direction of right-hand rule})$$

where α is the angle between the direction of the current and the magnetic field.



Example from Section 33.8:

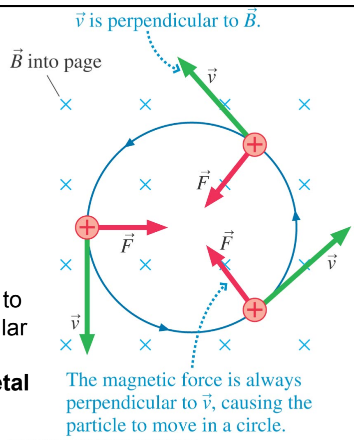
- Two parallel wires of length l are separated by a distance d. They carry currents in opposite directions: I_1 and I_2.

a) Will the force between them be attractive or repulsive?

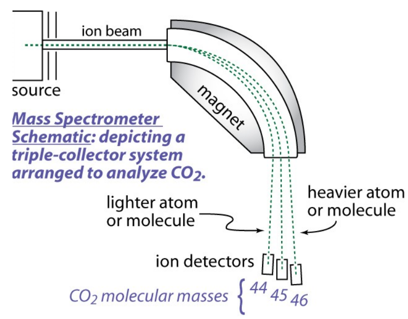
b) What is the magnitude of the force on either wire?

Magnetic Force is important for fast moving electrons or positive ions in a vacuum.

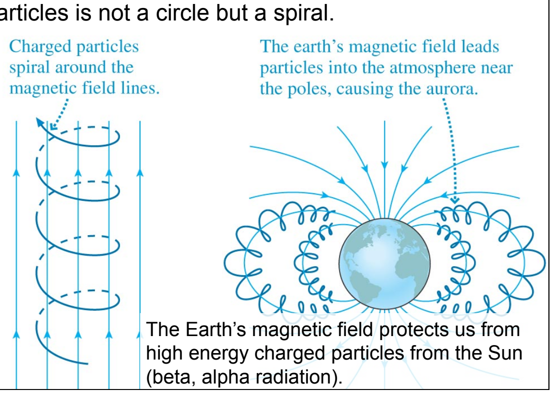
Since F tends to be perpendicular to v, it forms a good **centripetal** force.



Mass Spectrometers use the fact that the radius of circular trajectory in a magnetic field depends on the mass of the particles.



Cyclotron Motion: in 3D the motion of charged particles is not a circle but a spiral.



The Earth's magnetic field protects us from high energy charged particles from the Sun (beta, alpha radiation).

Aurora Borealis is natural light caused by charged particles accelerating in the Earth's magnetic field.

Ch. 35: The Galilean Transformations

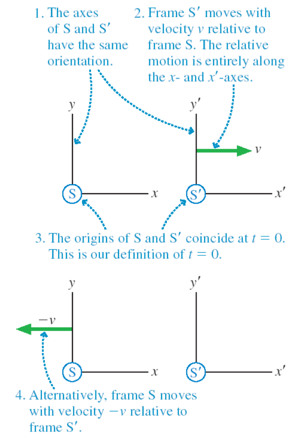
Consider two reference frames S and S′. The coordinate axes in S are x, y, z and those in S′ are x', y', z'. Reference frame S′ moves with velocity v relative to S along the x-axis. Equivalently, S moves with velocity −v relative to S′.

The *Galilean transformations of position* are:

$$x = x' + vt \qquad x' = x - vt$$
$$y = y' \qquad \text{or} \qquad y' = y$$
$$z = z' \qquad z' = z$$

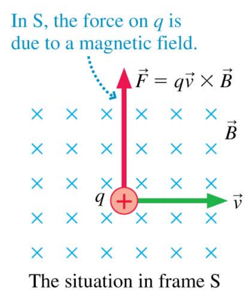
The *Galilean transformations of velocity* are:

$$u_x = u'_x + v \qquad u'_x = u_x - v$$
$$u_y = u'_y \qquad \text{or} \qquad u'_y = u_y$$
$$u_z = u'_z \qquad u'_z = u_z$$



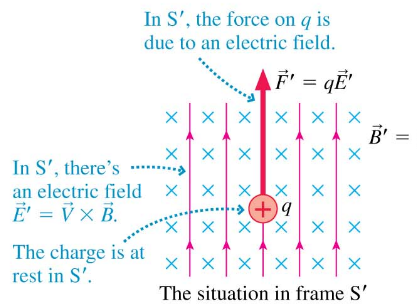
E or *B*? It Depends on Your Perspective

FIGURE 35.4 A charge moves through a magnetic field in frame S and experiences a magnetic force.



E or *B*? It Depends on Your Perspective

FIGURE 35.5 In frame S′ the charge experiences an electric force.



E or *B*? It Depends on Your Perspective

The **Galilean field transformation** equations are

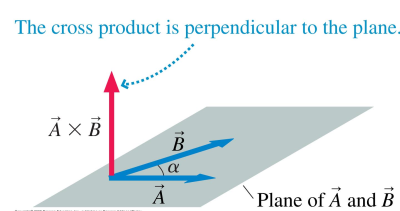
$$\vec{E}' = \vec{E} + \vec{V} \times \vec{B} \qquad \text{or} \qquad \vec{E} = \vec{E}' - \vec{V} \times \vec{B}'$$
$$\vec{B}' = \vec{B} - \frac{1}{c^2}\vec{V} \times \vec{E} \qquad \qquad \vec{B} = \vec{B}' + \frac{1}{c^2}\vec{V} \times \vec{E}'$$

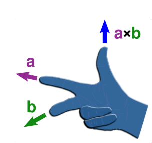
where V is the velocity of frame S′ relative to frame S and where the fields are measured *at the same point in space* by experimenters *at rest* in each reference frame.

NOTE: These equations are only valid if $V << c$.

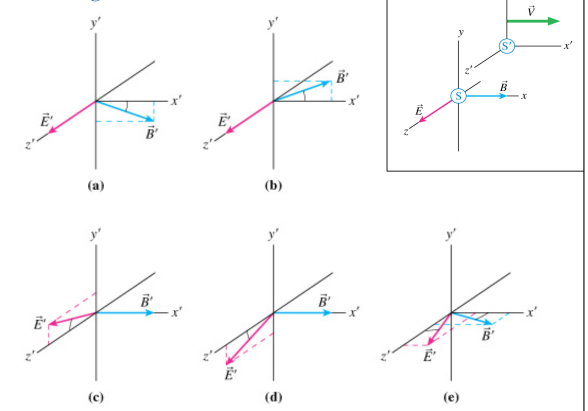
E or *B*? It Depends on Your Perspective

Recall the cross-product, first studied in Chapter 12, PHY131:





Which diagram shows the fields in frame S′?

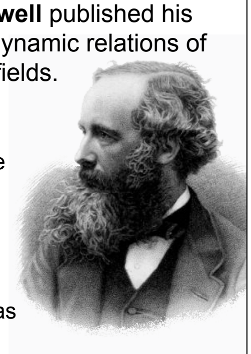


Maxwell's Equations

$\oint \vec{E}\cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$	Gauss's law
$\oint \vec{B}\cdot d\vec{A} = 0$	Gauss's law for magnetism
$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi_m}{dt}$	Faraday's law
$\oint \vec{B}\cdot d\vec{s} = \mu_0 I_{through} + \epsilon_0\mu_0\frac{d\Phi_e}{dt}$	Ampère-Maxwell law

History of Light

- 1864 – **James Clerk Maxwell** published his equations describing the dynamic relations of the electric and magnetic fields.



- Maxwell showed that disturbances in the electric and magnetic fields could propagate as a transverse wave, and he solved for the theoretical speed of this wave.
- This speed was very close to the current experimental value, justifying his theory that light was an electromagnetic wave.

Electromagnetic Waves

Maxwell, using his equations of the electromagnetic field, was the first to understand that light is an oscillation of the electromagnetic field. Maxwell was able to predict that

- Electromagnetic waves can exist at any frequency, not just at the frequencies of visible light. This prediction was the harbinger of radio waves.
- All electromagnetic waves travel in a vacuum with the same speed, a speed that we now call the *speed of light.*

$$v_{em} = \frac{1}{\sqrt{\epsilon_0\mu_0}} = 3.00 \times 10^8 \text{ m/s} = c$$