## AP Physics

### Chapter 29 (The Arrival of M) Problem Set

#### Subset #1: Due Friday 4/8
- P29.2 figure it out yourself
- P29.4 figure it out yourself
- P29.6 48.9° or 131°
- P29.8 13.2E-19 N (See pg. 338 for X product help)
- P29.11
- P29.13

#### Subset #2: Due Monday 4/11
- P29.24 a) 4.31E7 rad/s  b) 5.17E7 m/s
- P29.25
- P29.35
- P29.43 MMMMMMMMMDONUTS!
- P29.48 a) 5.41 mA m²  b) 4.33 mN m
- P29.51
- P29.65
Determine the initial direction of the deflection of charged particles as they enter the magnetic fields shown in Figure P29.2.

P29.2 See ANS. FIG. P29.2 for right-hand rule diagrams for each of the situations.

(a) up
(b) out of the page, since the charge is negative.
(c) no deflection
(d) into the page
4. Consider an electron near the Earth’s equator. In which direction does it tend to deflect if its velocity is (a) directed downward? (b) Directed northward? (c) Directed westward? (d) Directed southeastward?

ANS. FIG. P29.4

P29.4 At the equator, the Earth’s magnetic field is horizontally north. Because an electron has negative charge, $\vec{F} = q\vec{v} \times \vec{B}$ is opposite in direction to $\vec{v} \times \vec{B}$.

Figures are drawn looking down.

(a) Down $\times$ North = East, so the force is directed \textbf{West}.

(b) North $\times$ North = $\sin 0^\circ = 0$: \textbf{Zero deflection}.

(c) West $\times$ North = Down, so the force is directed \textbf{Up}.

(d) Southeast $\times$ North = Up, so the force is \textbf{Down}.
A proton moving at $4.00 \times 10^6$ m/s through a magnetic field of magnitude 1.70 T experiences a magnetic force of magnitude $8.20 \times 10^{-13}$ N. What is the angle between the proton’s velocity and the field?

\[
\theta = \sin^{-1} \left( \frac{F_B}{qvB} \right)
\]

\[
\theta = \sin^{-1} \left( \frac{8.20 \times 10^{-13} \text{ N}}{(1.60 \times 10^{-19} \text{ C})(4.00 \times 10^6 \text{ m/s})(1.70 \text{ T})} \right)
\]

\[
\theta = 48.9^\circ \text{ or } 131^\circ
\]
8. A proton moves with a velocity of \( \vec{v} = (2\hat{i} - 4\hat{j} + \hat{k}) \text{ m/s} \) in a region in which the magnetic field is \( \vec{B} = (\hat{i} + 2\hat{j} - \hat{k}) \text{T} \). What is the magnitude of the magnetic force this particle experiences?

\[
\vec{F}_B = q \vec{v} \times \vec{B} = (1.60 \times 10^{-19} \text{ C}) \left[ (2\hat{i} - 4\hat{j} + \hat{k}) \text{m/s} \times (\hat{i} + 2\hat{j} - \hat{k}) \text{T} \right]
\]

Since \( 1 \text{ C} \cdot \text{m} \cdot \text{T/s} = 1 \text{ N} \), we can write this in determinant form as:

\[
\vec{F}_B = (1.60 \times 10^{-19} \text{ N}) \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 2 & -4 & 1 \\ 1 & 2 & -1 \end{vmatrix}
\]

Expanding the determinant as described in Equation 11.8, we have

\[
\vec{F}_{B,x} = (1.60 \times 10^{-19} \text{ N}) \left[ (-4)(-1) - (1)(2) \right] \hat{i} \\
\vec{F}_{B,y} = (1.60 \times 10^{-19} \text{ N}) \left[ (1)(1) - (2)(-1) \right] \hat{j} \\
\vec{F}_{B,z} = (1.60 \times 10^{-19} \text{ N}) \left[ (2)(2) - (1)(-4) \right] \hat{k}
\]

Again in unit-vector notation,

\[
\vec{F}_B = (1.60 \times 10^{-19} \text{ N})(2\hat{i} + 3\hat{j} + 8\hat{k})
\]

\[
= (3.20\hat{i} + 4.80\hat{j} + 12.8\hat{k}) \times 10^{-19} \text{ N}
\]

\[
|\vec{F}_B| = \left( \sqrt{3.20^2 + 4.80^2 + 12.8^2} \right) \times 10^{-19} \text{ N} = 13.2 \times 10^{-19} \text{ N}
\]
Problem 29.11

A proton moves perpendicular to a uniform magnetic field \( \mathbf{B} \) at a speed of \( 1.00 \times 10^7 \) m/s and experiences an acceleration of \( 2.00 \times 10^{13} \) m/s\(^2\) in the positive \( x \) direction when its velocity is in the positive \( z \) direction. Determine the magnitude and direction of the field.

\[
F = ma = \left(1.67 \times 10^{-27} \text{ kg}\right) \left(2.00 \times 10^{13} \text{ m/s}^2\right) = 3.34 \times 10^{-14} \text{ N} = qvB \sin 90^\circ
\]

\[
B = \frac{F}{qv} = \frac{3.34 \times 10^{-14} \text{ N}}{\left(1.60 \times 10^{-19} \text{ C}\right)\left(1.00 \times 10^7 \text{ m/s}\right)} = 2.09 \times 10^{-2} \text{ T} = 20.9 \times 10^{-3} \text{ T}
\]

\[
= 20.9 \text{ mT}
\]

From ANS. FIG. P29.11, the right-hand rule shows that \( B \) must be in the \(-y\) direction to yield a force in the \(+x\) direction when \( v \) is in the \( z \) direction. Therefore,

\[
\mathbf{B} = -20.9 \mathbf{j} \text{ mT}
\]
13. An electron moves in a circular path perpendicular to a uniform magnetic field with a magnitude of 2.00 mT. If the speed of the electron is \(1.50 \times 10^7\) m/s, determine (a) the radius of the circular path and (b) the time interval required to complete one revolution.

(a) The magnetic force acting on the electron provides the centripetal acceleration, holding the electron in the circular path. Therefore, 
\[
F = qvB \sin 90^\circ = m_e v^2 / r,
\]
or
\[
r = \frac{m_e v}{eB} = \frac{(9.11 \times 10^{-31} \text{ kg}) (1.50 \times 10^7 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(2.00 \times 10^{-3} \text{ T})}
\]
\[
= 0.0427 \text{ m} = 4.27 \text{ cm}
\]

(b) The time to complete one revolution around the orbit (i.e., the period) is
\[
T = \frac{\text{distance traveled}}{\text{constant speed}} = \frac{2\pi r}{v} = \frac{2\pi (0.0427 \text{ m})}{1.50 \times 10^7 \text{ m/s}} = 1.79 \times 10^{-8} \text{ s}
\]
A cyclotron designed to accelerate protons has a magnetic field of magnitude 0.450 T over a region of radius 1.20 m. What are (a) the cyclotron frequency and (b) the maximum speed acquired by the protons?

(a) The name “cyclotron frequency” refers to the angular frequency or angular speed
\[ \omega = \frac{qB}{m} \]

For protons,
\[ \omega = \frac{(1.60 \times 10^{-19} \text{ C})(0.450 \text{ T})}{1.67 \times 10^{-27} \text{ kg}} = 4.31 \times 10^7 \text{ rad/s} \]

(b) The path radius is \( R = \frac{mv}{Bq} \).

Just before the protons escape, their speed is
\[ v = \frac{BqR}{m} = \frac{(0.450 \text{ T})(1.60 \times 10^{-19} \text{ C})(1.20 \text{ m})}{1.67 \times 10^{-27} \text{ kg}} = 5.17 \times 10^7 \text{ m/s} \]
25. Consider the mass spectrometer shown schematically in Figure 29.14. The magnitude of the electric field between the plates of the velocity selector is $2.50 \times 10^3$ V/m, and the magnetic field in both the velocity selector and the deflection chamber has a magnitude of 0.035 T. Calculate the radius of the path for a singly charged ion having a mass $m = 2.18 \times 10^{-26}$ kg.

**P29.25** In the velocity selector,

$$v = \frac{E}{B} = \frac{2500 \text{ V/m}}{0.035 \text{ T}} = 7.14 \times 10^4 \text{ m/s}$$

In the deflection chamber,

$$r = \frac{mv}{qB} = \frac{(2.18 \times 10^{-26} \text{ kg})(7.14 \times 10^4 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(0.035 \text{ T})} = 0.278 \text{ m}$$
35. A wire carries a steady current of 2.40 A. A straight section of the wire is 0.750 m long and lies along the $x$ axis within a uniform magnetic field, $\mathbf{B} = 1.60 \mathbf{k}$ T. If the current is in the positive $x$ direction, what is the magnetic force on the section of wire?

P22.35 The vector magnetic force on the wire is

$$\mathbf{F}_B = I \mathbf{l} \times \mathbf{B} = (2.40 \text{ A})(0.750 \text{ m})\mathbf{i} \times (1.60 \text{ T})\mathbf{k} = (-2.88 \mathbf{j}) \text{ N}$$
Assume the Earth’s magnetic field is 52.0 \( \mu \text{T} \) northward at 60.0° below the horizontal in Atlanta, Georgia. A tube in a neon sign stretches between two diagonally opposite corners of a shop window—which lies in a north–south vertical plane—and carries current 35.0 mA. The current enters the tube at the bottom south corner of the shop’s window. It exits at the opposite corner, which is 1.40 m farther north and 0.850 m higher up. Between these two points, the glowing tube spells out DONUTS. Determine the total vector magnetic force on the tube. Hint: You may use the first “important general statement” presented in the Finalize section of Example 29.4.

P29.43 Take the \( x \) axis east, the \( y \) axis up, and the \( z \) axis south. The field is

\[
\vec{B} = (52.0 \ \mu \text{T} \cos 60.0^\circ \hat{k}) + (52.0 \ \mu \text{T} \sin 60.0^\circ \hat{j})
\]

The current then has equivalent length:

\[
\vec{L}' = 1.40 \text{ m} \hat{k} + 0.850 \text{ m} \hat{j}
\]

The magnetic force is then

\[
\vec{F}_B = \vec{I}\vec{L}' \times \vec{B} = (0.0350 \ \text{A}) (0.850\hat{j} - 1.40\hat{k}) \text{ m} \times (-45.0\hat{j} - 26.0\hat{k}) \times 10^{-6} \ \text{T}
\]

\[
\vec{F}_B = 3.50 \times 10^{-8} \ \text{N} (-22.1\hat{i} - 63.0\hat{j}) = 2.98 \times 10^{-6} \ \text{N} (-\hat{i})
\]

\[= 2.98 \ \mu \text{N west}\]
48. A current of 17.0 mA is maintained in a single circular loop of 2.00 m circumference. A magnetic field of 0.800 T is directed parallel to the plane of the loop.
(a) Calculate the magnetic moment of the loop.
(b) What is the magnitude of the torque exerted by the magnetic field on the loop?

P29.48  
(a) From the circumference of the loop, $2\pi r = 2.00$ m, we find its radius to be $r = 0.318$ m. The magnitude of the magnetic moment is then

$$\mu = IA = \left(17.0 \times 10^{-3} \text{ A}\right) \left[\pi (0.318)^2 \text{ m}^2\right] = 5.41 \text{ mA} \cdot \text{m}^2$$

(b) The torque on the loop is given by Equation 29.17, $\tau = \vec{\mu} \times \vec{B}$, and its magnitude is

$$\tau = \left(5.41 \times 10^{-3} \text{ A} \cdot \text{m}^2\right)(0.800 \text{ T}) = 4.33 \text{ mN} \cdot \text{m}$$
A rectangular coil consists of \( N = 100 \) closely wrapped turns and has dimensions \( a = 0.400 \text{ m} \) and \( b = 0.300 \text{ m} \). The coil is hinged along the \( y \) axis, and its plane makes an angle \( \theta = 30.0^\circ \) with the \( x \) axis (Fig. P29.51).

(a) What is the magnitude of the torque exerted on the coil by a uniform magnetic field \( B = 0.800 \text{ T} \) directed in the positive \( x \) direction when the current is \( I = 1.20 \text{ A} \) in the direction shown? (b) What is the expected direction of rotation of the coil?

\[
\tau = NBAI \sin \phi
\]

\[
\tau = 100(0.800 \text{ T})(0.400 \times 0.300 \text{ m}^2) \times (1.20 \text{ A}) \sin 60^\circ
\]

\[
\tau = 9.98 \text{ N} \cdot \text{m}
\]

(b) Note that \( \phi \) is the angle between the magnetic moment and the \( \vec{B} \) field. The loop will rotate so as to align the magnetic moment with the \( \vec{B} \) field, clockwise as seen looking down from a position on the positive \( y \) axis.
65. **Review.** A 0.200-kg metal rod carrying a current of 10.0 A glides on two horizontal rails 0.500 m apart. If the coefficient of kinetic friction between the rod and rails is 0.100, what vertical magnetic field is required to keep the rod moving at a constant speed?

![Diagram of a rod on rails with a magnetic field B and force diagram](image)

P29.65 From the particle in equilibrium model,

\[ \sum F_y = 0: \quad +n - mg = 0 \]

\[ \sum F_x = 0: \quad -f_k + F_B = -\mu_k n + IBd \sin 90.0^\circ = 0 \]

Solving for the magnetic field gives

\[ B = \frac{\mu_k mg}{ld} = \frac{0.100(0.200 \text{ kg})(9.80 \text{ m/s}^2)}{(10.0 \text{ A})(0.500 \text{ m})} = 39.2 \text{ mT} \]