PHYSICS II

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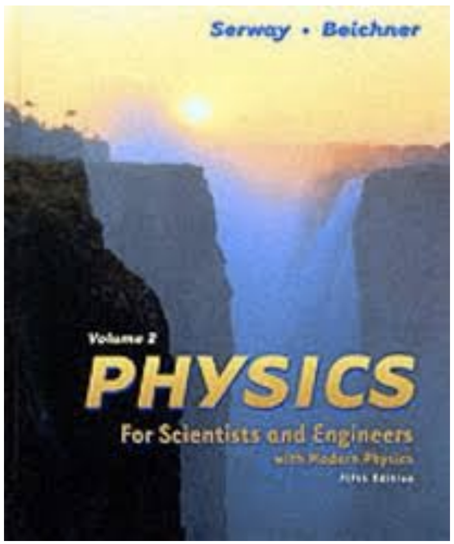
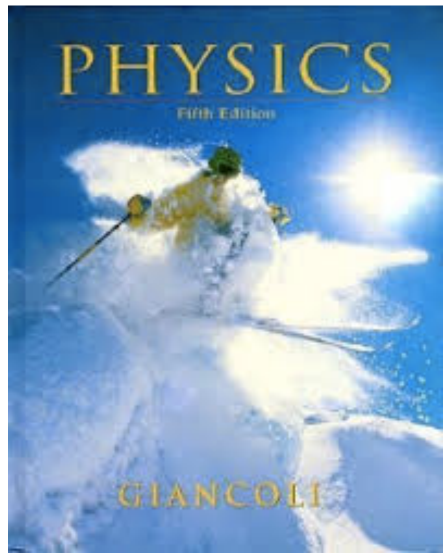
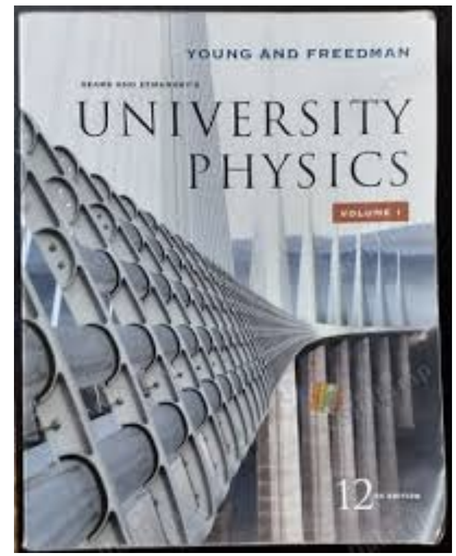
References for this lecture:







An electron in a television picture tube moves toward the front of the tube with a speed of 8.0×10^6 m/s along the x axis (Fig. 29.5). Surrounding the neck of the tube are coils of wire that create a magnetic field of magnitude 0.025 T, directed at an angle of 60° to the x axis and lying in the xy plane.

(A) Calculate the magnetic force on the electron using Equation 29.2.

Solution Using Equation 29.2, we find the magnitude of the magnetic force:

$$\begin{aligned} F_B &= |q|vB\sin\theta \\ &= (1.6 \times 10^{-19}\ \text{C})(8.0 \times 10^6\ \text{m/s})(0.025\ \text{T})(\sin 60°) \\ &= \boxed{2.8 \times 10^{-14}\ \text{N}} \end{aligned}$$

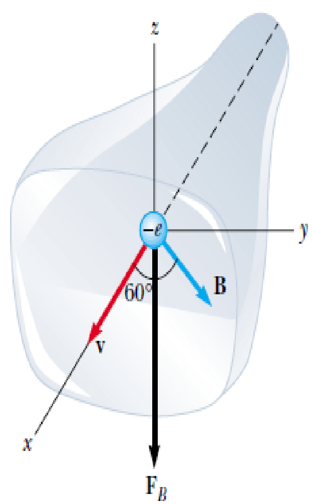


Figure 29.5 (Example 29.1) The magnetic force $\mathbf{F}_B$ acting on the electron is in the negative z direction when $\mathbf{v}$ and $\mathbf{B}$ lie in the xy plane.

Because $\mathbf{v} \times \mathbf{B}$ is in the positive z direction (from the right-hand rule) and the charge is negative, $\mathbf{F}_B$ is in the negative z direction.

(B) Find a vector expression for the magnetic force on the electron using Equation 29.1.

Solution We begin by writing a vector expression for the velocity of the electron:

$$\mathbf{v} = (8.0 \times 10^6\ \hat{\mathbf{i}})\ \text{m/s}$$

and one for the magnetic field:

$$\begin{aligned} \mathbf{B} &= (0.025\cos 60°\,\hat{\mathbf{i}} + 0.025\sin 60°\,\hat{\mathbf{j}})\text{T} \\ &= (0.013\,\hat{\mathbf{i}} + 0.022\,\hat{\mathbf{j}})\text{T} \end{aligned}$$

The force on the electron, using Equation 29.1, is

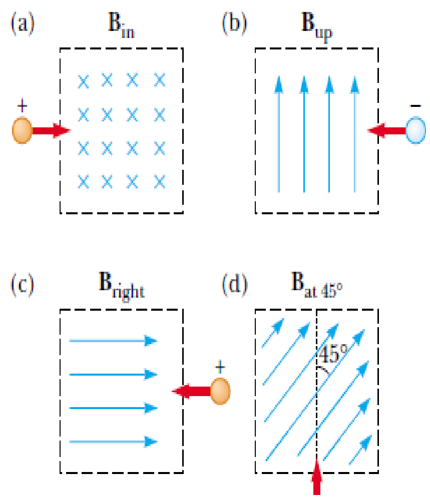
$$\begin{aligned} \mathbf{F}_B &= q\mathbf{v} \times \mathbf{B} \\ &= (-e)[(8.0 \times 10^6\,\hat{\mathbf{i}})\ \text{m/s}] \times [(0.013\,\hat{\mathbf{i}} + 0.022\,\hat{\mathbf{j}})\text{T}] \\ &= (-e)[(8.0 \times 10^6\,\hat{\mathbf{i}})\ \text{m/s}] \times [(0.013\,\hat{\mathbf{i}})\text{T}] \\ &\quad + (-e)[(8.0 \times 10^6\,\hat{\mathbf{i}})\ \text{m/s}] \times [(0.022\,\hat{\mathbf{j}})\text{T}] \\ &= (-e)(8.0 \times 10^6\ \text{m/s})(0.013\ \text{T})(\hat{\mathbf{i}} \times \hat{\mathbf{i}}) \\ &\quad + (-e)(8.0 \times 10^6\ \text{m/s})(0.022\ \text{T})(\hat{\mathbf{i}} \times \hat{\mathbf{j}}) \\ &= (-1.6 \times 10^{-19}\ \text{C})(8.0 \times 10^6\ \text{m/s})(0.022\ \text{T})\,\hat{\mathbf{k}} \end{aligned}$$

where we have used Equations 11.7a and 11.7b to evaluate $\hat{\mathbf{i}} \times \hat{\mathbf{i}}$ and $\hat{\mathbf{i}} \times \hat{\mathbf{j}}$. Carrying out the multiplication, we find,

$$\mathbf{F}_B = \boxed{(-2.8 \times 10^{-14}\ \text{N})\hat{\mathbf{k}}}$$

This expression agrees with the result in part (A). The magnitude is the same as we found there, and the force vector is in the negative z direction.

1. Determine the initial direction of the deflection of charged particles as they enter the magnetic fields as shown in Figure P29.1.

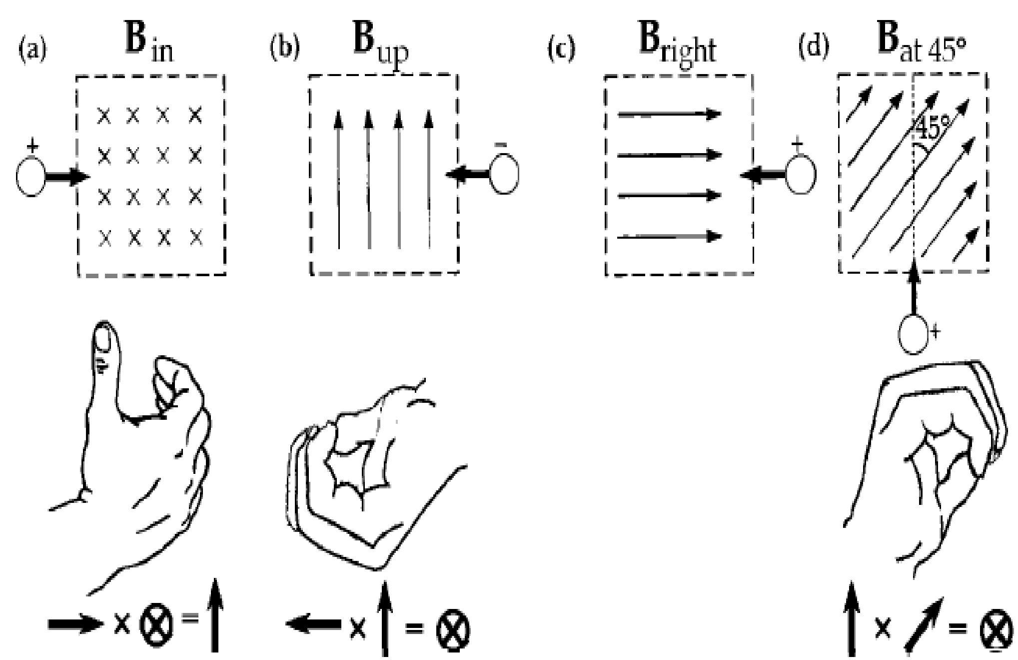


P29.1 (a) up

(b) out of the page, since the charge is negative.

(c) no deflection

(d) into the page



5. A proton moves perpendicular to a uniform magnetic field **B** at 1.00×10^7 m/s and experiences an acceleration of 2.00×10^{13} m/s^2 in the $+x$ direction when its velocity is in the $+z$ direction. Determine the magnitude and direction of the field.

P29.5

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

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

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.

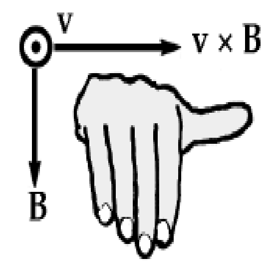


FIG. P29.5

9. A proton moves with a velocity of $\mathbf{v} = (2\hat{\mathbf{i}} - 4\hat{\mathbf{j}} + \hat{\mathbf{k}})$ m/s in a region in which the magnetic field is $\mathbf{B} = (\hat{\mathbf{i}} + 2\hat{\mathbf{j}} - 3\hat{\mathbf{k}})$ T. What is the magnitude of the magnetic force this charge experiences?

P29.9 $\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$

$$\mathbf{v} \times \mathbf{B} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ +2 & -4 & +1 \\ +1 & +2 & -3 \end{vmatrix} = (12-2)\hat{\mathbf{i}} + (1+6)\hat{\mathbf{j}} + (4+4)\hat{\mathbf{k}} = 10\hat{\mathbf{i}} + 7\hat{\mathbf{j}} + 8\hat{\mathbf{k}}$$

$$|\mathbf{v} \times \mathbf{B}| = \sqrt{10^2 + 7^2 + 8^2} = 14.6 \text{ T} \cdot \text{m/s}$$

$$|\mathbf{F}_B| = q|\mathbf{v} \times \mathbf{B}| = (1.60 \times 10^{-19} \text{ C})(14.6 \text{ T} \cdot \text{m/s}) = \boxed{2.34 \times 10^{-18} \text{ N}}$$

57. A positive charge $q = 3.20 \times 10^{-19}$ C moves with a velocity $\mathbf{v} = (2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - \hat{\mathbf{k}})$ m/s through a region where both a uniform magnetic field and a uniform electric field exist. (a) Calculate the total force on the moving charge (in unit-vector notation), taking $\mathbf{B} = (2\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + \hat{\mathbf{k}})$ T and $\mathbf{E} = (4\hat{\mathbf{i}} - \hat{\mathbf{j}} - 2\hat{\mathbf{k}})$ V/m. (b) What angle does the force vector make with the positive x axis?

P29.57 (a) The net force is the Lorentz force given by

$$\mathrm{F} = q\mathrm{E} + q\mathbf{v} \times \mathrm{B} = q(\mathrm{E} + \mathbf{v} \times \mathrm{B})$$

$$\mathrm{F} = \left(3.20 \times 10^{-19}\right)\left[\left(4\hat{\mathbf{i}} - 1\hat{\mathbf{j}} - 2\hat{\mathbf{k}}\right) + \left(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 1\hat{\mathbf{k}}\right) \times \left(2\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + 1\hat{\mathbf{k}}\right)\right] \mathrm{N}$$

Carrying out the indicated operations, we find:

$$\mathrm{F} = \boxed{\left(3.52\hat{\mathbf{i}} - 1.60\hat{\mathbf{j}}\right) \times 10^{-18}\ \mathrm{N}}.$$

(b)

$$\theta = \cos^{-1}\left(\frac{F_x}{F}\right) = \cos^{-1}\left(\frac{3.52}{\sqrt{(3.52)^2 + (1.60)^2}}\right) = \boxed{24.4^\circ}$$

Example 29.2 Force on a Semicircular Conductor

A wire bent into a semicircle of radius R forms a closed circuit and carries a current I. The wire lies in the xy plane, and a uniform magnetic field is directed along the positive y axis, as shown in Figure 29.12. Find the magnitude and direction of the magnetic force acting on the straight portion of the wire and on the curved portion.

Solution The magnetic force $\mathbf{F}_1$ acting on the straight portion has a magnitude $F_1 = ILB = 2IRB$ because $L = 2R$ and

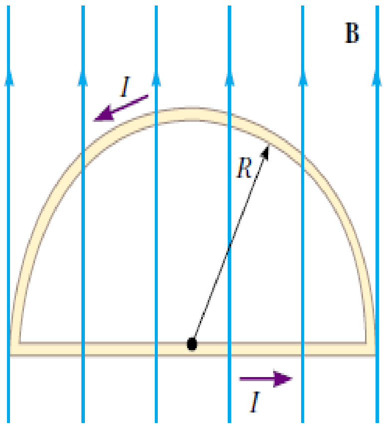


Figure 29.12 (Example 29.2) The net magnetic force acting on a closed current loop in a uniform magnetic field is zero. In the setup shown here, the magnetic force on the straight portion of the loop is $2IRB$ and directed out of the page, and the magnetic force on the curved portion is $2IRB$ directed into the page.

the wire is oriented perpendicular to $\mathbf{B}$. The direction of $\mathbf{F}_1$ is out of the page based on the right-hand rule for the cross product $\mathbf{L} \times \mathbf{B}$.

To find the magnetic force $\mathbf{F}_2$ acting on the curved part, we use the results of Case 1. The magnetic force on the curved portion is the same as that on a straight wire of length $2R$ carrying current I to the left. Thus, $F_2 = ILB = 2IRB$. The direction of $\mathbf{F}_2$ is into the page based on the right-hand rule for the cross product $\mathbf{L} \times \mathbf{B}$.

Because the wire lies in the xy plane, the two forces on the loop can be expressed as

$$\mathbf{F}_1 = 2IRB\hat{\mathbf{k}}$$

$$\mathbf{F}_2 = -2IRB\hat{\mathbf{k}}$$

The net magnetic force on the loop is

$$\sum \mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 = 2IRB\hat{\mathbf{k}} - 2IRB\hat{\mathbf{k}} = 0$$

Note that this is consistent with Case 2, because the wire forms a closed loop in a uniform magnetic field.

12. 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, $\mathbf{B} = 1.60\hat{\mathbf{k}}$ T. If the current is in the $+x$ direction, what is the magnetic force on the section of wire?

P29.12 $\mathbf{F}_B = I\boldsymbol{\ell} \times \mathbf{B} = (2.40\text{ A})(0.750\text{ m})\hat{\mathbf{i}} \times (1.60\text{ T})\hat{\mathbf{k}} = \boxed{\left(-2.88\hat{\mathbf{j}}\right)\text{ N}}$

A proton is moving in a circular orbit of radius 14 cm in a uniform 0.35-T magnetic field perpendicular to the velocity of the proton. Find the linear speed of the proton.

Solution From Equation 29.13, we have

$$v = \frac{qBr}{m_p} = \frac{(1.60 \times 10^{-19}\text{ C})(0.35\text{ T})(0.14\text{ m})}{1.67 \times 10^{-27}\text{ kg}}$$

$$= 4.7 \times 10^6\text{ m/s}$$

In an experiment designed to measure the magnitude of a uniform magnetic field, electrons are accelerated from rest through a potential difference of 350 V. The electrons travel along a curved path because of the magnetic force exerted on them, and the radius of the path is measured to be 7.5 cm. (Fig. 29.20 shows such a curved beam of electrons.) If the magnetic field is perpendicular to the beam,

(A) what is the magnitude of the field?

$$K_i = 0 \text{ and } K_f = \tfrac{1}{2} m_e v^2,$$

$$\Delta K + \Delta U = 0 \longrightarrow \tfrac{1}{2} m_e v^2 + (-e)\,\Delta V = 0$$

$$v = \sqrt{\frac{2e\,\Delta V}{m_e}} = \sqrt{\frac{2(1.60 \times 10^{-19}\ \text{C})(350\ \text{V})}{9.11 \times 10^{-31}\ \text{kg}}}$$

$$= 1.11 \times 10^7\ \text{m/s}$$

Now, using Equation 29.13, we find

$$B = \frac{m_e v}{er} = \frac{(9.11 \times 10^{-31}\ \text{kg})(1.11 \times 10^7\ \text{m/s})}{(1.60 \times 10^{-19}\ \text{C})(0.075\ \text{m})}$$

$$= 8.4 \times 10^{-4}\ \text{T}$$

(B) What is the angular speed of the electrons?

$$\omega = \frac{v}{r} = \frac{1.11 \times 10^7\ \text{m/s}}{0.075\ \text{m}} = 1.5 \times 10^8\ \text{rad/s}$$

To finalize this problem, note that the angular speed can be represented as $\omega = (1.5 \times 10^8\ \text{rad/s})(1\ \text{rev}/2\pi\ \text{rad}) = 2.4 \times 10^7\ \text{rev/s}$. The electrons travel around the circle 24 million times per second! This is consistent with the very high speed that we found in part (A).

29. The magnetic field of the Earth at a certain location is directed vertically downward and has a magnitude of 50.0 μT. A proton is moving horizontally toward the west in this field with a speed of 6.20×10^6 m/s. (a) What are the direction and magnitude of the magnetic force the field exerts on this charge? (b) What is the radius of the circular arc followed by this proton?

P29.29 (a) $B = 50.0 \times 10^{-6}\ \text{T};\ v = 6.20 \times 10^6\ \text{m/s}$

Direction is given by the right-hand-rule: $\boxed{\text{southward}}$

$F_B = qvB\sin\theta$

$F_B = \left(1.60 \times 10^{-19}\ \text{C}\right)\left(6.20 \times 10^6\ \text{m/s}\right)\left(50.0 \times 10^{-6}\ \text{T}\right)\sin 90.0°$

$= \boxed{4.96 \times 10^{-17}\ \text{N}}$

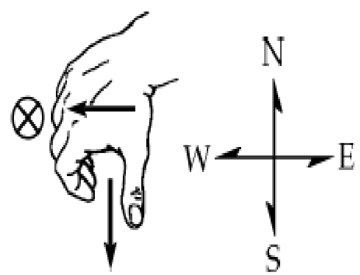


FIG. P29.29

(b) $$F = \frac{mv^2}{r} \text{ so } r = \frac{mv^2}{F} = \frac{\left(1.67 \times 10^{-27}\ \text{kg}\right)\left(6.20 \times 10^6\ \text{m/s}\right)^2}{4.96 \times 10^{-17}\ \text{N}} = \boxed{1.29\ \text{km}}$$