8.2 Magnetic Force on Moving Charges

If you place a compass needle next to a conductor, then connect the conductor to a DC power supply, the compass needle turns, demonstrating that the current in the conductor produces a magnetic field (**Figure 1**), which interacts with the magnetic field of the compass needle. Therefore, a current can exert a force on a magnet. Hence two conductors with currents can experience a force between each other: place two conductors (wires) side by side, both with a current passing through them, and they will attract or repel each other. This means that a magnetic field can exert a force on a current, or moving charges. One can argue that this follows from Newton's third law: if a current produces a force on a magnet, then the magnet must produce an equal but opposite force on the current.

(a) (b)

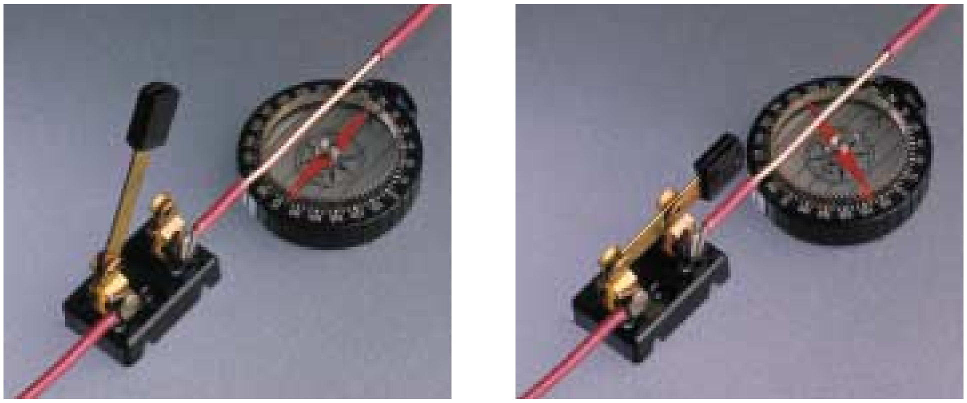


Figure 1
(a) The compass needle points north when there is no current in the wire.
(b) The magnetic compass needle turns when there is a current in the wire. If Earth's magnetic field were not present, the compass needle would be exactly perpendicular to the wire.

INVESTIGATION 8.2.1

Magnetic Force on a Moving Charge (p. 421)
How is the motion of a charged particle influenced by a magnetic field? How could you test your predictions with an experiment or simulation? Investigation 8.2.1 at the end of the chapter will allow you to check your answers.

This principle explains some natural phenomena such as the spectacular light displays of the aurora borealis and aurora australis and the methods bees use for navigation. This principle also has many technological applications, including television tubes and the technology used by particle physicists in particle accelerators and chemists in laboratory mass spectrographs.

To better understand the magnetic force on a moving charge, we need to find the factors that affect the force and eventually find an equation for the force. When a charged particle enters a magnetic field at an angle to the field lines, it experiences a force and the path of the particle curves. If the particle does not escape the field, it will follow a circular path (**Figure 2**). Investigation 8.2.1 explores the path followed by charged particles in magnetic fields and the factors that affect the path.

(a) (b) (c)

Figure 2
(a) A traditional cathode-ray tube showing a beam of electrons
(b) The beam curves in a magnetic field.
(c) A beam of electrons is bent into a circular path by the uniform magnetic field from a pair of Helmholtz coils. The pale purple glow is caused by ionized gas, created when electrons collide with atoms in the imperfect vacuum of the tube.

Measuring Magnetic Fields

The magnitude of the magnetic force $\vec{F}_M$ on a charged particle

- is directly proportional to the magnitude of the magnetic field $\vec{B}$, the velocity $\vec{v}$, and the charge q of the particle.
- depends on the angle θ between the magnetic field $\vec{B}$ and the velocity $\vec{v}$. When $\theta = 90°$ (particle is moving perpendicular to the field lines), the force is at a maximum, and when $\theta = 0°$ or $180°$ (particle is moving parallel to the field lines), the force vanishes. This is consistent with the fact that the magnitude of the magnetic force experienced by the charged particle is also proportional to $\sin \theta$.

Combining these factors gives

$$F_M = qvB \sin \theta$$

where F_M is the magnitude of the force on the moving charged particle, in newtons; q is the amount of charge on the moving particle, in coulombs; v is the magnitude of the velocity of the moving particle, in metres per second; B is the magnitude of the magnetic field strength, in teslas (SI unit, T; 1 T = 1 kg/C·s); and θ is the angle between $\vec{v}$ and $\vec{B}$.

This equation specifies the magnitude of the force but not its direction. Consider a plane parallel to both the magnetic field $\vec{B}$ and the velocity $\vec{v}$ of a charged particle; the force is perpendicular to this plane. A simple right-hand rule can be used to determine the direction of the force as follows: if the right thumb points in the direction of motion of a positive charge, and the extended fingers point in the direction of the magnetic field, the force is in the direction in which the right palm would push (**Figure 3**).

If the charge is negative, reverse the direction of your thumb when using the rule. (In other words, point your thumb in the opposite direction of the velocity of the charge.) This works because a negative charge flowing in one direction is equivalent to a positive charge flowing in the opposite direction.

The *Yamato 1* (**Figure 4**) is the first ship to apply this principle in propulsion. Instead of using propellers, it uses magnetohydrodynamic (MHD) propulsion; that is, it exerts

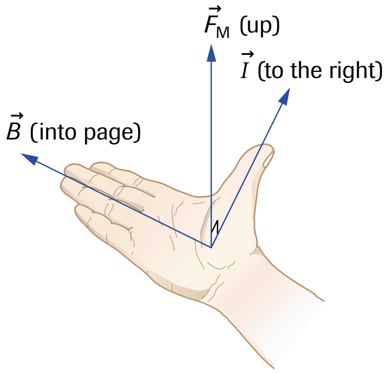


Figure 3
The right-hand rule specifies the direction of the magnetic force.

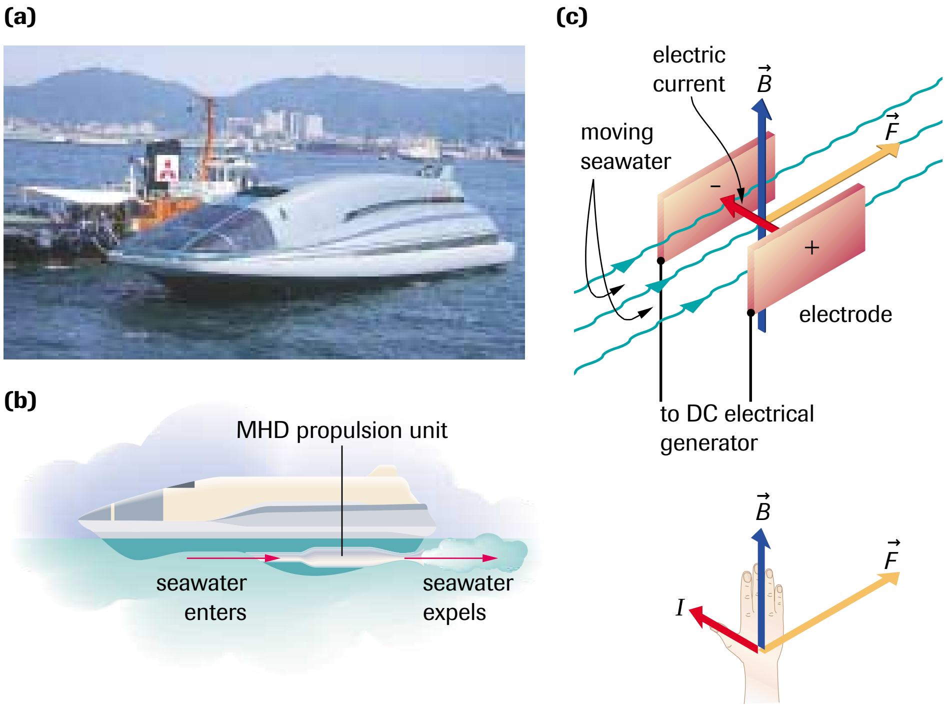


Figure 4
(a) The *Yamato 1*
(b) The MHD propulsion unit pushes seawater backward, moving the ship forward.
(c) Use the right-hand rule to determine the direction of the force on the seawater.

TRY THIS activity

The Vector or Cross Product

The equation for the force on a moving charge in a magnetic field stems from the vector or cross product of two vectors defined by the equation $\vec{C} = \vec{A} \times \vec{B}$. The magnitude and direction of this vector can be found in Appendix A. Let $\vec{A}$ represent the charge multiplied by the velocity and $\vec{B}$ represent the magnetic field.

(a) Show that the cross product can be used to derive the magnitude of the magnetic force on a charged particle moving in an external magnetic field.

(b) Verify that the direction of the force found by applying the right-hand rule for the cross product is the same as the direction obtained using the right-hand rule described earlier.

a magnetic force on a current. A typical MHD propulsion unit uses a large superconducting magnet to create a strong magnetic field. Large metal parallel plates connected to either side of the unit have a large potential difference across them caused by a DC electric generator. This creates an electric current in the seawater (due to the presence of ions) perpendicular to the magnetic field. Using the right-hand rule with your thumb in the direction of the positive charge and fingers in the direction of the magnetic field, your palm will push in the direction of the force on the charges (ions) causing the seawater to be pushed out the back of the unit. According to Newton's third law, if the unit pushes the water out the back of the ship, the water will exert an equal and opposite force on the unit (ship), causing it to move forward.

MHD propulsion is promising because it offers the prospect of an inexpensive alternative to bulky, expensive, fuel-burning marine engines. Since there are no propellers, drive shafts, gears, or engine pistons, noise levels are minimized, and maintenance costs could also prove low.

LEARNING TIP

In the Page or Out?
One way to remember which way is which is to imagine a dart that has an X for a tail when it is moving away from you and a point as it moves toward a dart board.

Let us now take a closer look at the trajectory of a charged particle in a magnetic field. Since $\vec{F}_M$ is always perpendicular to $\vec{v}$, it is a purely deflecting force, meaning it changes the direction of $\vec{v}$ but has no effect on the magnitude of the velocity or speed. This is true because no component of the force acts in the direction of motion of the charged particle. As a result, the magnetic field does not change the energy of the particle and does no work on the particle.

Figure 5 shows a positively charged particle in a magnetic field perpendicular to its velocity. (If the particle were negative, its trajectory would curve the other way, in a clockwise circle.) If the magnetic force is the sole force acting on the particle, it is equal to the net force on the particle and is always perpendicular to its velocity. This is the condition for uniform circular motion; in fact, if the field is strong enough and the particle doesn't lose any energy, it will move in a complete circle as shown.

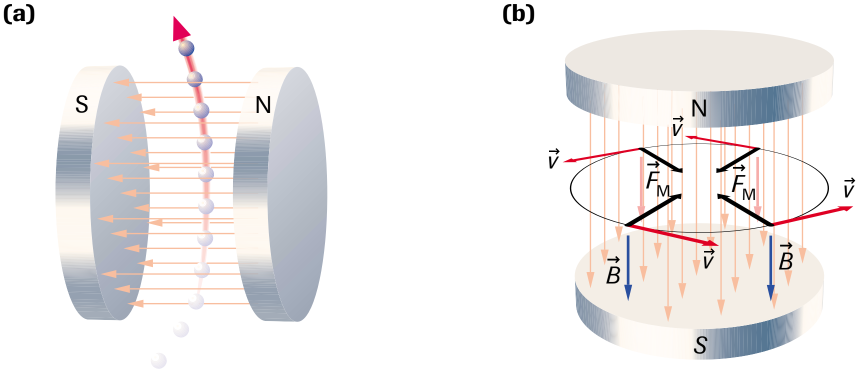


Figure 5
(a) A positive charge moving at constant speed through a uniform magnetic field follows a curved path.
(b) Ideally, a charged particle will move in a circle because the magnetic force is perpendicular to the velocity at all times.

We represent these magnetic fields in two-dimensional diagrams by drawing Xs for field lines directed into and perpendicular to the page and dots for field lines pointing out of and perpendicular to the page. If the velocity is perpendicular to the magnetic field lines, then both the velocity and the magnetic force are parallel to the page, as in **Figure 6.**

SAMPLE problem 1

An electron accelerates from rest in a horizontally directed electric field through a potential difference of 46 V. The electron then leaves the electric field, entering a magnetic field of magnitude 0.20 T directed into the page (**Figure 7**).

(a) Calculate the initial speed of the electron upon entering the magnetic field.

(b) Calculate the magnitude and direction of the magnetic force on the electron.

(c) Calculate the radius of the electron's circular path.

Solution

$\Delta V = 46$ V $\qquad v = ?$

$B = 0.20$ T $= 0.20$ kg/C·s $\qquad F_M = ?$

$m_e = 9.11 \times 10^{-31}$ kg (from Appendix C) $\qquad r = ?$

$q = 1.6 \times 10^{-19}$ C

(a) The electric potential energy lost by the electron in moving through the electric potential difference equals its gain in kinetic energy:

$$-\Delta E_E = \Delta E_K$$

$$q\Delta V = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2q\Delta V}{m}}$$

$$= \sqrt{\frac{2(1.6 \times 10^{-19}\ \text{C})(46\ \text{V})}{9.11 \times 10^{-31}\ \text{kg}}}$$

$$v = 4.0 \times 10^6\ \text{m/s}$$

The initial speed of the electron upon entering the magnetic field is 4.0×10^6 m/s.

(b)
$$F_M = qvB \sin\theta$$

$$= (1.6 \times 10^{-19}\ \text{C})(4.0 \times 10^6\ \text{m/s})(0.20\ \text{kg/C·s}) \sin 90^\circ$$

$$F_M = 1.3 \times 10^{-13}\ \text{N}$$

The magnitude of the force is 1.3×10^{-13} N.

To apply the right-hand rule, point your right thumb in the direction opposite to the velocity, as required for a negative charge. Point your fingers into the page and perpendicular to it. Your palm now pushes toward the bottom of the page. Therefore, $\vec{F}_M = 1.3 \times 10^{-13}$ N [down].

(c) Since the magnetic force is the only force acting on the electron and it is always perpendicular to the velocity, the electron undergoes uniform circular motion. The magnetic force is the net (centripetal) force:

$$F_M = F_c$$

$$qvB = \frac{mv^2}{r} \qquad \text{(since } \sin 90^\circ = 1\text{)}$$

or
$$r = \frac{mv}{Bq}$$

$$= \frac{(9.11 \times 10^{-31}\ \text{kg})(4.0 \times 10^6\ \text{m/s})}{(0.20\ \text{T})(1.6 \times 10^{-19}\ \text{C})}$$

$$r = 1.1 \times 10^{-4}\ \text{m}$$

The radius of the circular path is 1.1×10^{-4} m.

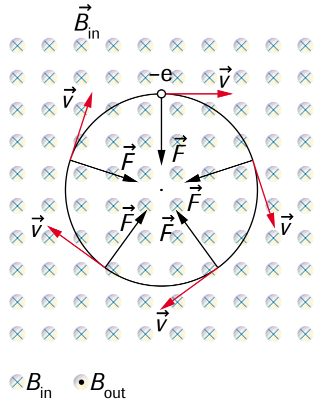


Figure 6
In this case, the particle is negatively charged, with the magnetic field directed into the page, perpendicular to the velocity. To determine the direction of the magnetic force, point your thumb in the opposite direction of the velocity because the charge is negative.

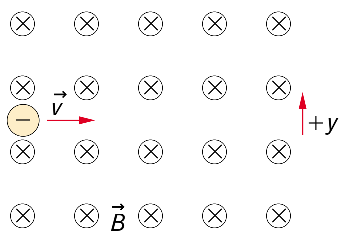


Figure 7
For Sample Problem 1

LEARNING TIP

In problems involving charged particles moving in an external magnetic field, the absolute value of the elementary charge $\left(|q| = 1.16 \times 10^{-19}\ \text{C}\right)$ will be used.

Answers

2. 1.7×10^{-14} N [E]
3. 0.16 T [horizontal, toward observer]
4. 0.13 m
5. 1.1×10^{7} m/s; 6.9×10^{5} V
6. 1.0 N

Practice

Understanding Concepts

1. Explain how the MHD propulsion system of the *Yamato 1* works.
2. Determine the magnitude and direction of the magnetic force on a proton moving horizontally northward at 8.6×10^{4} m/s, as it enters a magnetic field of 1.2 T directed vertically upward. (The mass of a proton is 1.67×10^{-27} kg.)
3. An electron moving through a uniform magnetic field with a velocity of 2.0×10^{6} m/s [up] experiences a maximum magnetic force of 5.1×10^{-14} N [left]. Calculate the magnitude and direction of the magnetic field.
4. Calculate the radius of the path taken by an α particle (He^{2+} ion, of charge 3.2×10^{-19} C and mass 6.7×10^{-27} kg) injected at a speed of 1.5×10^{7} m/s into a uniform magnetic field of 2.4 T, at right angles to the field.
5. Calculate the speed of a proton, moving in a circular path of radius 8.0 cm, in a plane perpendicular to a uniform 1.5-T magnetic field. What voltage would be required to accelerate the proton from rest, in a vacuum, to this speed? ($m_{proton} = 1.67 \times 10^{-27}$ kg)
6. An airplane flying through Earth's magnetic field at a speed of 2.0×10^{2} m/s acquires a charge of 1.0×10^{2} C. Calculate the maximum magnitude of the magnetic force on it in a region where the magnitude of Earth's magnetic field is 5.0×10^{-5} T.

DID YOU KNOW?

Cathode Rays

The beam of electrons was called a cathode ray because the electron had not yet been discovered. The old terminology survives in electronic engineering, where a cathode-ray tube is any tube constructed along Thomson's lines—whether in a computer monitor, a television, or an oscilloscope.

Charge-to-Mass Ratios

The British scientist J.J. Thomson (1856–1940) used the apparatus in **Figure 8** to accelerate a thin beam of electrons between the parallel plates and the coils. Applying either an electric field or a magnetic field across the tube caused the beam to be deflected up, down, left, or right relative to its original path, depending on the direction of the applied field. In all cases, the direction of deflection was consistent with a stream of negatively charged particles. Thomson concluded that cathode rays consist of negatively charged particles moving at high speed from the cathode to the anode. He called these particles electrons.

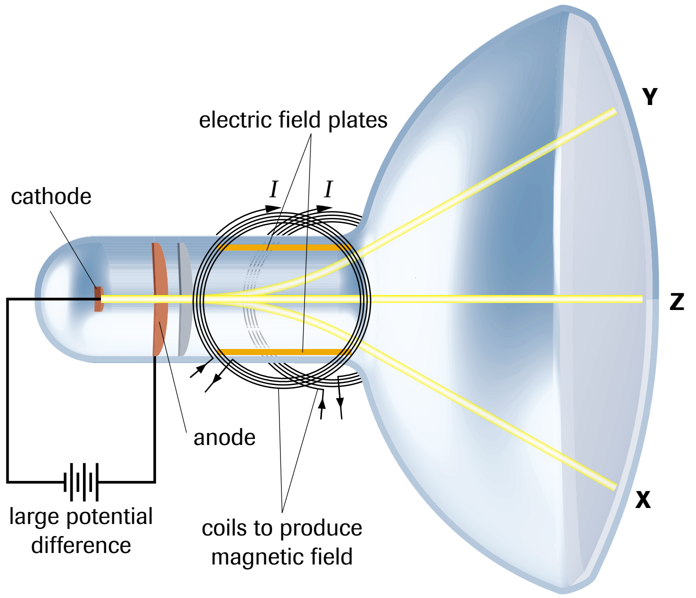


Figure 8
Thomson's cathode-ray tube. The path of the electron is curved only in the magnetic field of the coils (along a circular arc) or the electric field of the plates (along a parabola). After leaving these fields, the electrons move, in a straight line, to points X or Y.

When there is a current in the coils, it creates a magnetic field of magnitude B, which deflects the electrons along a circular arc of radius r so that they hit the end of the tube at point X. From our previous work on magnetic deflection, we know that

$$F_M = F_c$$

$$evB = \frac{mv^2}{r} \quad \text{(since } \sin 90° = 1\text{)}$$

or

$$\frac{e}{m} = \frac{v}{Br}$$

We can calculate B if we know the physical dimensions of the coils and the amount of current flowing through them. We can measure r directly.

To determine the electron's speed v, Thomson used a set of parallel plates. When a potential difference is applied to the plates (with the lower plate negative) and there is no current in the coils, an electron is deflected upward, reaching the end of the tube at point Y. (For an electron moving at a typical laboratory speed, the effect of gravitation is negligible.) With current in the coils and a magnetic field again acting on the electrons, the potential difference across the plates can be adjusted until the two deflections (electric and magnetic) cancel, causing the electron beam to reach the end of the tube at point Z. When this has been done,

$$F_M = F_E$$

$$evB = e\varepsilon$$

or

$$v = \frac{\varepsilon}{B}$$

where ε is the magnitude of the electric field between the parallel plates $\left(\varepsilon = \frac{V}{d}\right)$. Conversely, this setup can be used as a "velocity selector," allowing only those particles with velocity equal to the ratio of the electric field over the magnetic field to pass through undeflected.

Thomson could now express the ratio of charge to mass for electrons (**Figure 9**) in terms of the measurable quantities of electric field strength, magnetic field strength, and radius of curvature:

$$\frac{e}{m} = \frac{v}{Br}$$

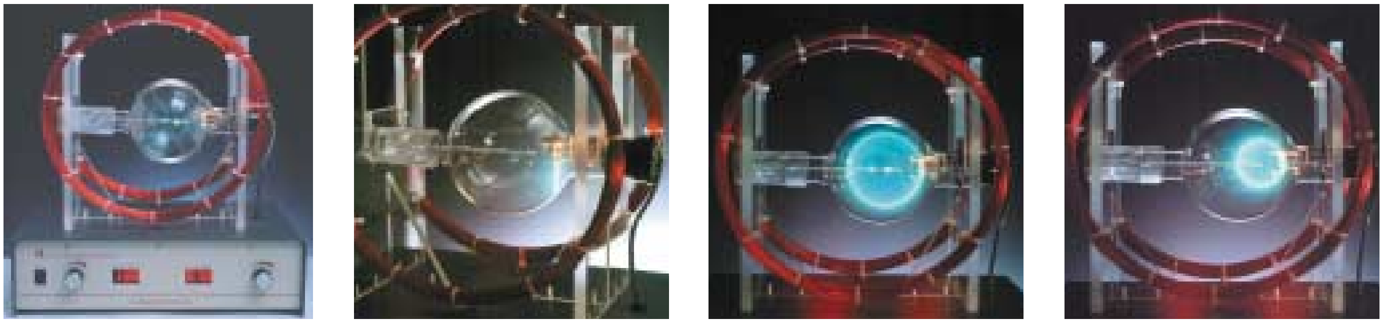
$$\frac{e}{m} = \frac{\varepsilon}{B^2 r}$$

The accepted value of the ratio of charge to mass for an electron is, to three significant figures,

$$\frac{e}{m} = 1.76 \times 10^{11} \text{ C/kg}$$

Figure 9
(a) The apparatus used to determine the e/m ratio
(b) The electrons in the beam move in a straight line vertically.
(c) The electrons move in a circular path in the magnetic field of the coils.
(d) Increasing the magnetic field strength decreases the radius of the path.

(a) **(b)** **(c)** **(d)**



A few years later, Millikan (as we saw in Section 7.5) determined the charge on an electron to be 1.60×10^{-19} C. Combining these two results, we find the electron mass to be 9.11×10^{-31} kg.

Thomson's technique may be used to determine the charge-to-mass ratio for any charged particle moving through known electric and magnetic fields under negligible gravitation. Upon measuring the radius of curvature of the particle trajectory in the magnetic field only, and then adjusting the electric field to produce no net deflection, the charge-to-mass ratio is found to be

$$\frac{q}{m} = \frac{\varepsilon}{B^2 r}$$

Thomson's research led to the development of the mass spectrometer, an instrument used for separating particles, notably ions, by mass. The particles are first accelerated by high voltages, then directed into a magnetic field perpendicular to their velocity. The particles follow different curved paths depending on their mass and charge.

SAMPLE problem 2

Calculate the mass of chlorine-35 ions, of charge 1.60×10^{-19} C, accelerated into a mass spectrometer through a potential difference of 2.50×10^2 V into a uniform 1.00-T magnetic field. The radius of the curved path is 1.35 cm.

Solution

$q = 1.60 \times 10^{-19}$ C

$\Delta V = 2.50 \times 10^2$ V

$B = 1.00\ \text{T} = 1.00\ \text{kg/C·s}$

$r = 1.35\ \text{cm} = 1.35 \times 10^{-2}$ m

$m = ?$

From $\Delta E_c = \Delta E_K$ and $F_M = F_c$, we have the following two equations:

$$qvB = \frac{mv^2}{r} \quad \text{and} \quad \frac{1}{2}mv^2 = q\Delta V$$

Isolating v in both

$$v = \frac{qBr}{m} \quad \text{and} \quad v = \sqrt{\frac{2qV}{m}}$$

Equating the two expressions for the speed:

$$\frac{qBr}{m} = \sqrt{\frac{2q\Delta V}{\text{m}}}$$

Squaring both sides:

$$\frac{q^2B^2r^2}{m^2} = \frac{2q\Delta V}{m}$$

$$m = \frac{qB^2r^2}{2\Delta V}$$

$$= \frac{(1.60 \times 10^{-19}\ \text{C})(1.00\ \text{kg/C·s})^2\,(1.35 \times 10^{-2}\ \text{m})^2}{2(2.50 \times 10^2\ \text{V})}$$

$$m = 5.83 \times 10^{-26}\ \text{kg}$$

The mass of the chlorine-35 ions is 5.83×10^{-26} kg.

Effects of Magnetic Fields

When electrons are not moving perpendicular to the magnetic field lines, the component of the velocity parallel to the lines is unaffected, and the component perpendicular to the field lines rotates as we saw before. Together, these two components combine to produce the spiralling motion of the particle. If the magnetic field is not uniform but increases in magnitude in the direction of motion, the force on the electron due to the magnetic field will slow the charges by reducing the component of the velocity parallel to the field and may even cause the spiralling electron to reverse direction, forming a magnetic mirror (**Figure 10**).

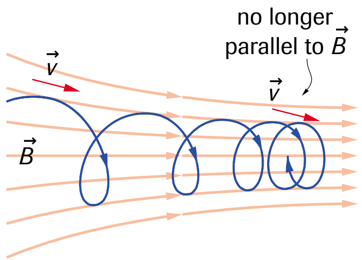
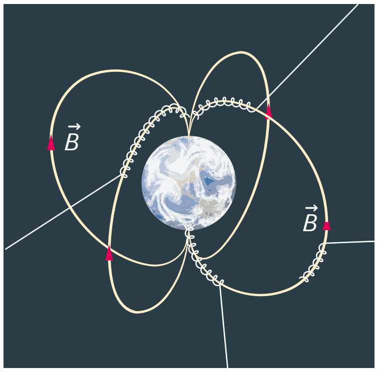


Figure 10
A magnetic mirror. The field becomes stronger in the direction of motion of the charged particle. The component of the velocity, initially parallel to the field lines, is reduced by the changing field, slowing the motion.

DID YOU KNOW?

Van Allen Belts
In the late 1950s, scientists believed that particles could be trapped by Earth's magnetic field but lacked proof. In 1958, James Van Allen, of the University of Iowa, built the small satellite *Explorer 1*, which carried one instrument: a Geiger counter. The experiment worked well at low altitudes. At the top of the orbit, however, no particles were counted. Two months later, a counter on *Explorer 3* revealed a very high level of radiation where *Explorer 1* had found none. It turns out that the first counter had detected so much radiation it was overwhelmed and gave a zero reading.

(a)



(b)

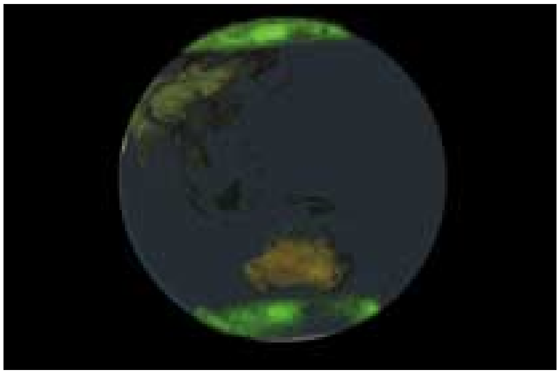


Figure 11
(a) Cosmic rays from the Sun and deep space consist of energetic electrons and protons. These particles often spiral around Earth's magnetic field lines toward the poles.
(b) The first spacecraft image to show auroras occurring simultaneously at both magnetic poles

Charged particles from the Sun (cosmic rays) enter Earth's atmosphere by spiralling around the magnetic field lines connecting Earth's two magnetic poles. As a result, the concentration of incoming particles is higher in polar regions than at the equator, where the charged particles must cross the magnetic field lines. These charged particles headed for the poles get trapped in spiral orbits about the lines instead of crossing them. Since the field strength increases near the poles the aurora borealis can occur in the Northern Hemisphere and the aurora australis in the Southern Hemisphere. Collisions between the charged particles and atmospheric atoms and molecules cause the spectacular glow of an aurora (**Figure 11**).

Earth has two major radiation belts, areas composed of charged particles trapped by the magnetic field of Earth (**Figure 12**). The radiation in these belts is so intense that it can damage sensitive electronic equipment in satellites; all types of spacecraft avoid them. The ring current, or outer belt, is approximately 25 500 km above the surface of Earth, and the inner belt—often called the Van Allen belt after its discoverer—is approximately 12 500 km above the surface of Earth. (The inner belt is now thought to consist of two belts.) The charged particles in these belts spiral around magnetic field lines and are often reflected away from the stronger fields near the poles.

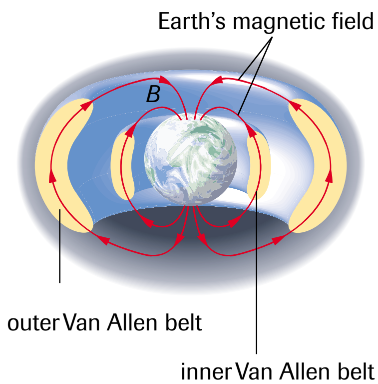


Figure 12
The radiation belts are formed by charged particles in cosmic rays trapped in Earth's magnetic field.

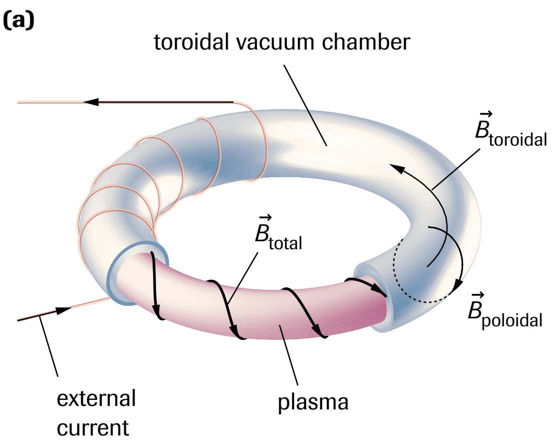


Figure 13
(a) Schematic of the toroidal plasma-containment chamber of a tokamak fusion reactor
(b) The inside of a tokamak

Magnetic field principles are applied in toroidal (i.e., doughnut-shaped) tokamak prototypes for nuclear-fusion reactors (**Figure 13**). This reactor design uses magnetic fields to contain the hot, highly ionized gases (plasmas) needed for a controlled thermonuclear reaction. It is hoped that controlled thermonuclear fusion will, some decades from now, provide abundant energy without the radioactive wastes characteristic of fission reactors.

Field Theory

It is easy to be satisfied with the concept of a force being transmitted from one object to another through direct contact: when your hand pushes on a book, the book moves, because both your hand and the book touch. But we have learned that all objects are composed of spatially separated atoms that interact but do not actually touch one another, so the concept of contact becomes meaningless. When your hand pushes on the book, it really involves electromagnetic forces between the electrons in each object.

To understand gravitational, electric, and magnetic forces we need the concept of a field. At first, fields were just a convenient way of describing the force in a region of space, but with the undeniable success of fields in describing different types of forces, field theory has developed into a general scientific model and is now viewed as a physical reality that links together different kinds of forces that might otherwise be seen as completely separate phenomena. Now we can say that if an object experiences a particular kind of force over a continuous range of positions, then a force field exists in that region. The concept of a field is of vast importance with wide-ranging applications, from describing the motion of the planets, to the interactions of charged particles in the atom.

Even though these three types of forces can be explained using fields, there are some obvious differences between the forces and the fields themselves as well as some striking similarities. The gravitational force—although considered the weakest of the three—controls the motion of celestial bodies reaching across the vast distances of space (**Figure 14**). The electric and magnetic forces are much stronger and have greater influence on the motion of charged particles such as electrons and protons.

The direction of the gravitational and electric forces is determined by the centre of mass of the objects in question or the centre of the charge distribution on the charges in question. However, the magnetic force is determined by the direction of motion of the charge with respect to the magnetic field, and the force is zero if the relative motion between the

Figure 14
The gravitational forces from the larger galaxy are causing the two galaxies to merge, a process that will take billions of years.

field and charge is zero. For the other two, the motion of the particle does not influence the direction of the force.

The two fields that are most closely related are the electric and magnetic fields. For both fields the appropriate particle is charged. The fields have also been linked through Maxwell's equations, which will be studied in more advanced courses, and they are used together to describe the properties of light and to discover the nature of matter and new particles in particle accelerators. In particle accelerators, electric fields are used to accelerate particles such as electrons and protons, and magnetic fields are used to steer them in huge circular paths (**Figure 15**). Particle accelerators will be revisited in Chapter 13.

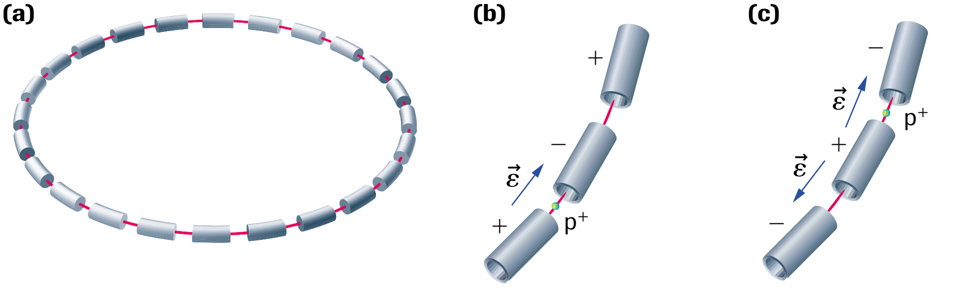


Figure 15
(a) A synchrotron consists of a ring of magnets and accelerating cylinders arranged in a circular tunnel.
(b) A particle passes through the gap between two charged cylinders.
(c) The charges on the cylinders are adjusted to keep the particle accelerating.

EXPLORE an issue

Decision-Making Skills
- ● Define the Issue
- ● Analyze the Issue
- ● Research
- ● Defend the Position
- ○ Identify Alternatives
- ● Evaluate

Government Spending on Developing New Technologies

A portion of the federal budget goes toward scientific research involving expensive new technologies (e.g., through the National Science and Engineering Research Council, NSERC). This support includes funding technologies that use gravitational, electric, and magnetic fields, for example, satellites. Many people think this money is well spent; others think it is not justified since it comes from public funds.

Take a Stand
Should public funds be spent on scientific research involving gravitational, electric, and magnetic fields to develop new technologies?

Forming an Opinion
In a group, choose a new technology that uses gravitational, electric, or magnetic fields, and discuss the social and economic impact on our society. Discuss the benefits and drawbacks both of this new technology and the spending of public funds on research. Research the Internet and/or other sources.

GO www.science.nelson.com

Develop a set of criteria that you will use to evaluate the social and economic impact of your chosen technology. Write a position paper in which you state your opinion, the criteria you used to evaluate social and economic impacts in forming your opinion, and any evidence or arguments that support your opinion. Your "paper" can be a Web page, a video, a scientific report, or some other creative way of communicating.

SUMMARY Magnetic Force on Moving Charges

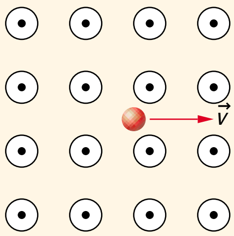
- A current can exert a force on a magnet, and a magnet can exert a force on a current.
- $F_M = qvB \sin \theta$
- The direction of the magnetic force is given by the right-hand rule.
- The speed of an electron in a cathode-ray tube can be determined with the help of magnetic deflecting coils and electric deflecting plates. The same apparatus then gives the charge-to-mass ratio of the electron. Combining this determination with the charge of an electron from the Millikan oil-drop experiment yields the mass of the electron.

Section 8.2 Questions

Understanding Concepts

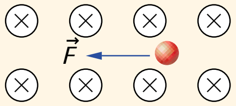
1. Determine the direction of the missing quantity for each of the diagrams in **Figure 16**.

(a)



positive charge
in a magnetic field

(b)



positive charge
in a magnetic field

Figure 16

2. A student charges an ebonite rod with a charge of magnitude 25 nC. The magnetic field in the lab due to Earth is 5.0×10^{-5} T [N]. The student throws the ebonite at 12 m/s [W]. Determine the resulting magnetic force.
3. If a magnet is brought close to the screen of a colour television, the tube can be permanently damaged (so don't do this). The magnetic field will deflect electrons, deforming the picture and also permanently magnetizing the TV (**Figure 17**). Calculate the radius of the circular path followed by an electron which, having been accelerated through an electric potential difference of 10.0 kV in the neck of the tube, enters a magnetic field of magnitude 0.40 T due to a strong magnet placed near the screen.

(a)

(b)

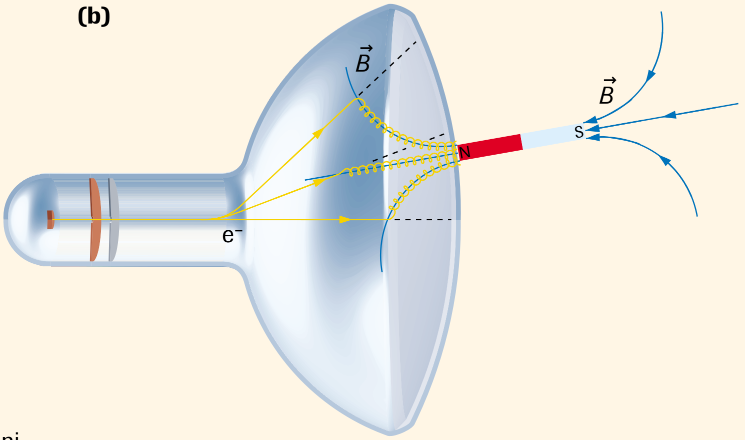


Figure 17
(a) A magnet can permanently damage a computer monitor or colour-television tube.
(b) Electrons spiral toward the screen in the field of the bar magnet.

4. An electron is at rest. Can this electron be set into motion by applying
   (a) a magnetic field?
   (b) an electric field?
   Explain your answers.
5. A charged particle is moving in a circle in a uniform magnetic field. A uniform electric field is suddenly created, running in the same direction as the magnetic field. Describe the motion of the particle.
6. Describe the left-hand rule for negatively charged particles in a magnetic field, and explain why it is equivalent to the right-hand rule for positively charged particles.
7. A charged particle moves with a constant velocity in a certain region of space. Could a magnetic field be present? Explain your answer.
8. A negatively charged particle enters a region with a uniform magnetic field perpendicular to the velocity of the particle. Explain what will happen to the kinetic energy of the particle.
9. Explain why magnetic field lines never cross.
10. How can you tell if moving electrons are being deflected by a magnetic field, an electric field, or both?
11. From space, a proton approaches Earth, toward the centre in the plane of the equator.
    (a) Which way will the proton be deflected? Explain your answer.
    (b) Which way would an electron be deflected under similar circumstances? Explain your answer.
    (c) Which way would a neutron be deflected under similar circumstances? Explain your answer.
12. (a) Define a field of force.
    (b) Compare the properties of gravitational, electric, and magnetic fields by completing **Table 1**.
    (c) Explain why field theory is considered a general scientific model.

Table 1

	Gravitational	Electric	Magnetic
appropriate particle	?	?	?
factors affecting magnitude of the force	?	?	?
relative strength	?	?	?

Applying Inquiry Skills

13. Explain the procedure you would use to show that charged particles spiral around magnetic field lines and even form a magnetic mirror when they are not moving perpendicular to the field. You may assume a strong magnet and a TV tube are available. (The tube will be permanently damaged in the experiment.)

Making Connections

14. Compare and contrast the energy source of the MHD marine propulsion unit with a typical jet engine.
15. A strong magnet is placed on the screen of a television set (permanently damaging the tube). Explain the following observations:
    (a) The picture becomes distorted.
    (b) The screen is completely dark where the field is strongest.
16. Naturally occurring charged particles in background radiation can damage human cells. How can magnetic fields be used to shield against them?
17. Thomson and Millikan deepened our understanding of the electrical nature of matter.
    (a) What principles of gravity, electricity, and magnetism did they apply in designing their experiments?
    (b) What technology was involved in these discoveries?
    (c) How did the use of this technology change our view of charge and the nature of matter?
18. Launching a satellite into orbit requires an understanding of gravitational, electric, and magnetic fields. Research how these three fields are important in designing a launch. Report on three different ways in which the development of launch technology has changed scientific theories (e.g., in weather patterns) or has affected society and the environment (e.g., with telecommunications or wildlife preservation).