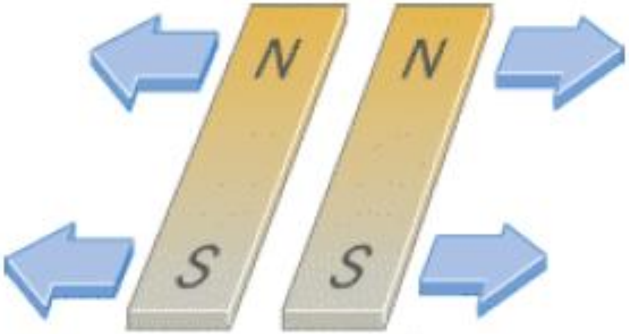
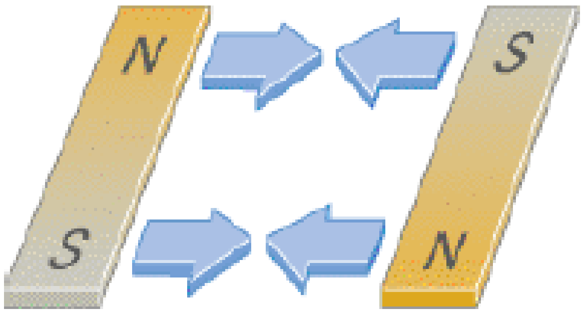
The magnetic forces



Like poles repel

(a)

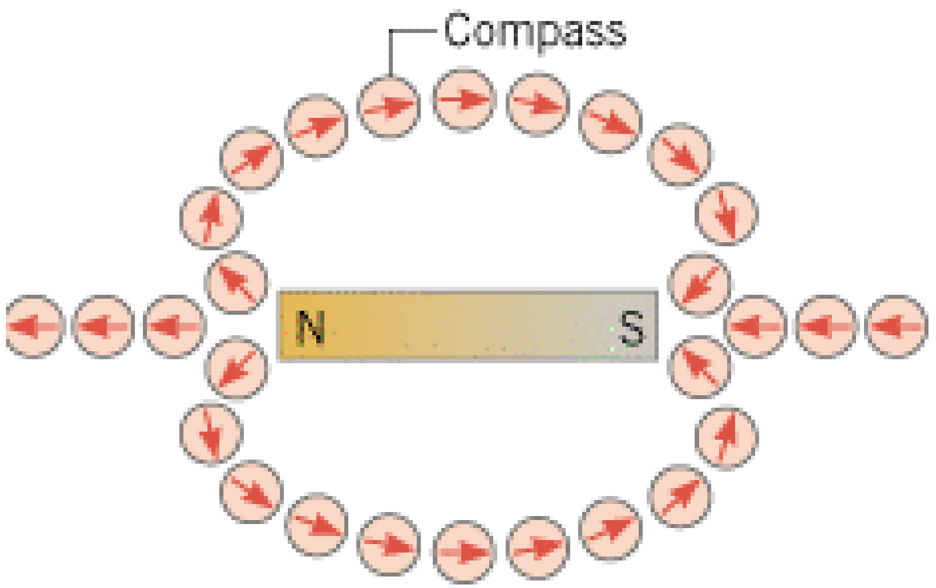


Unlike poles attract

(b)

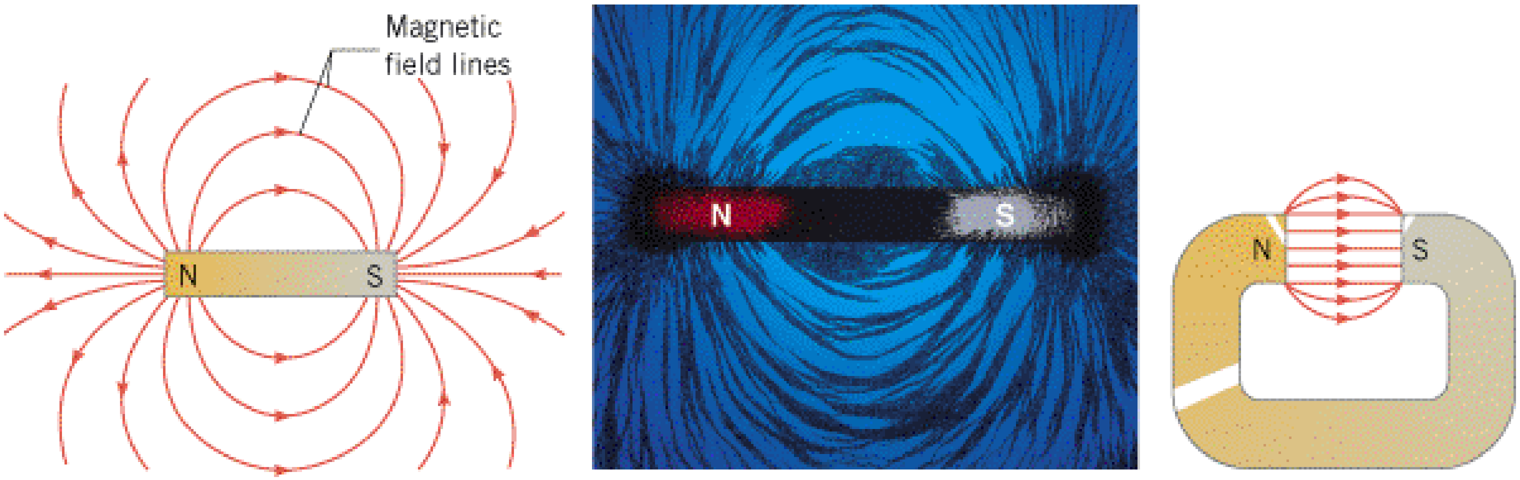
Like poles repel each other, and unlike poles attract.

The magnetic field



- A **magnetic field** exists in the region around a magnet. The magnetic field is a vector that has both magnitude and direction.
- ***The direction of the magnetic field at any point in space is the direction indicated by the north pole of a small compass needle placed at that point.***

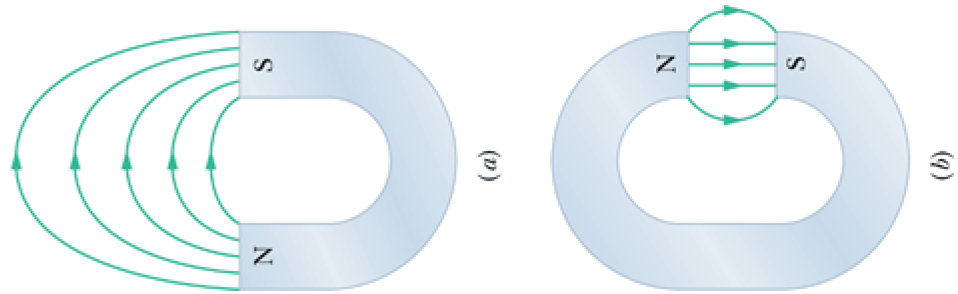
The magnetic field line



(a) (b) (c)

- The lines originate from the north pole and end on the south pole; they do not start or stop in midspace.
- The magnetic field at any point is tangent to the magnetic field line at that point.
- The strength of the field is proportional to the number of lines per unit area that passes through a surface oriented perpendicular to the lines.
- The magnetic field lines will never come to cross each other.

What Produces a Magnetic Field?

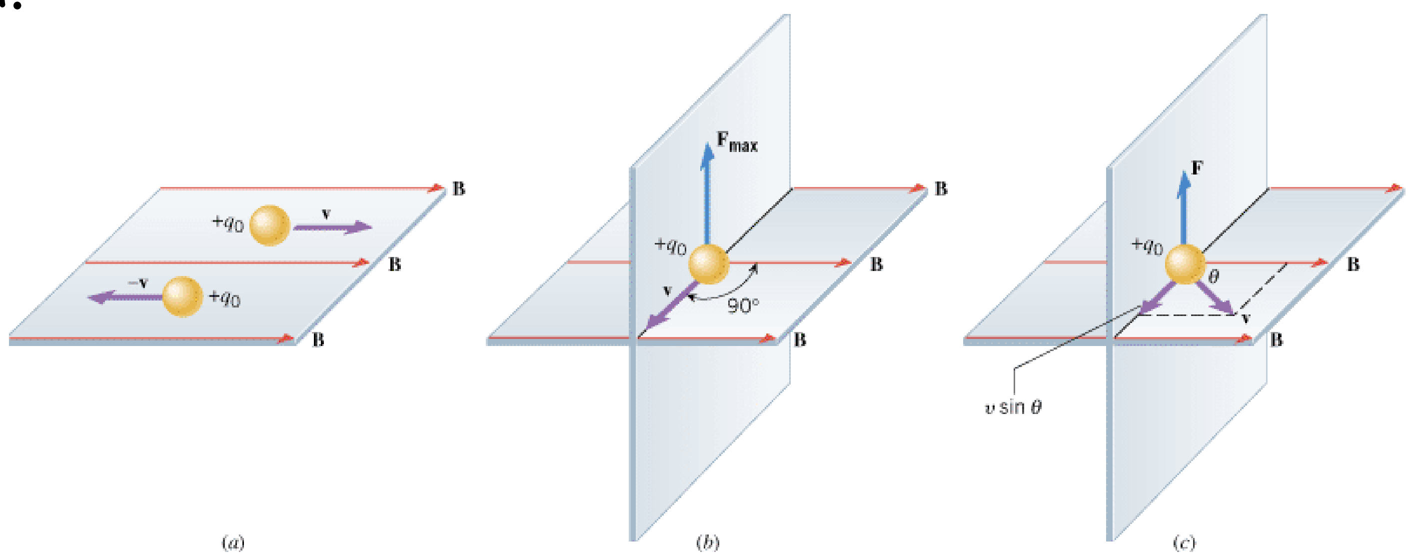


- Moving electrically charged particles, such as a current, produce a magnetic field
- **Permanent magnet.** Elementary particles such as electrons have an *intrinsic* magnetic field around them. The magnetic fields of the electrons in certain materials add together to give a net magnetic field around the material. Such addition is the reason why a **permanent magnet** has a permanent magnetic field. In other materials, the magnetic fields of the electrons cancel out, giving no net magnetic field surrounding the material

Magnetic force on a Charged Particle

When a charge is placed in a magnetic field, it experiences a magnetic force if two conditions are met:

1. The charge must be moving. No magnetic force acts on a stationary charge.
2. The velocity of the moving charge must have a component that is perpendicular to the direction of the field.

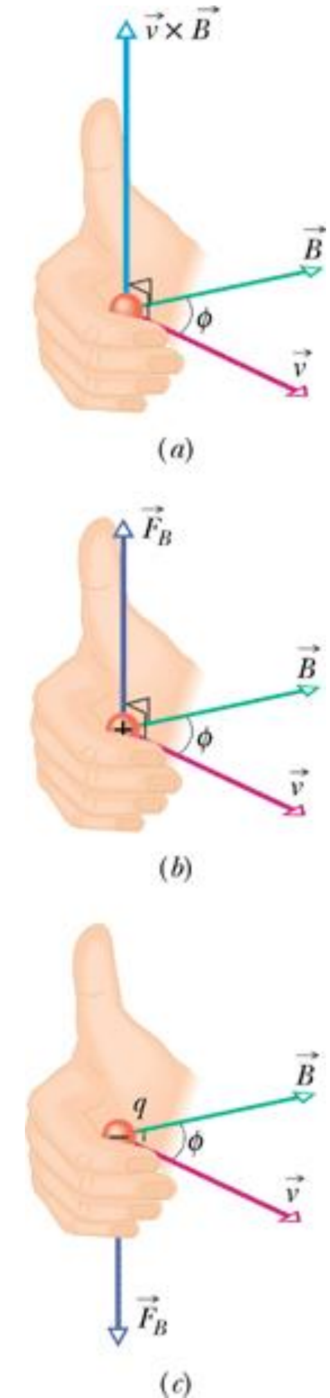


Magnetic force on a Charged Particle

$$\overrightarrow{F_B} = q\overrightarrow{v} \times \overrightarrow{B};$$

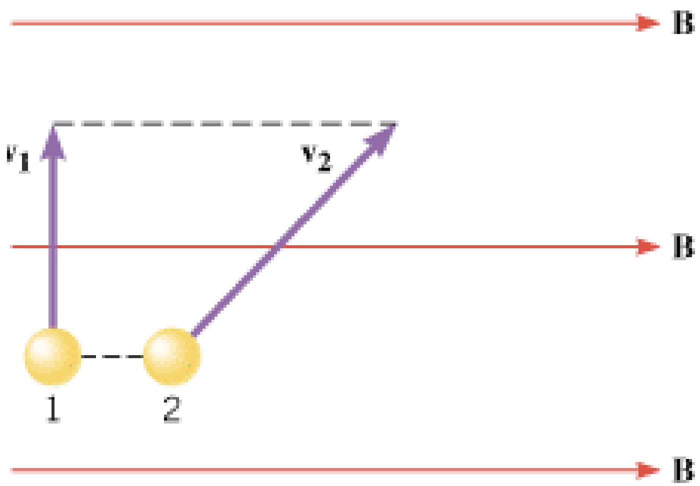
Right-Hand Rule

The force $\overrightarrow{F_B}$ acting on a charged particle moving with velocity $\overrightarrow{v}$ through a magnetic field $\overrightarrow{B}$ is *always* perpendicular to $\overrightarrow{v}$ and $\overrightarrow{B}$.



Check Your Understanding

Two particles, having the same charge but different velocities, are moving in a constant magnetic field (see the drawing, where the velocity vectors are drawn to scale). Which particle, if either, experiences the greater magnetic force? (a) Particle 1 experiences the greater force, because it is moving perpendicular to the magnetic field. (b) Particle 2 experiences the greater force, because it has the greater speed. (c) Particle 2 experiences the greater force, because a component of its velocity is parallel to the magnetic field. (d) Both particles experience the same magnetic force, because the component of each velocity that is perpendicular to the magnetic field is the same.



Example 1 Magnetic Forces on Charged Particles

A proton in a particle accelerator has a speed of 5.0×10^6 m/s. The proton encounters a magnetic field whose magnitude is 0.40 T and whose direction makes an angle of $\theta = 30.0°$ with respect to the proton's velocity. Find (a) the magnitude and direction of the magnetic force on the proton and (b) the acceleration of the proton. The Mass of proton is 1.67×10^{-27} kg.

The Definition of Magnetic Field

- The magnetic field B is a vector, and its direction is direction is along the zero-force axis.
- The magnitude B of the magnetic field at any point in space is defined as

$$B = \frac{F}{q_0(v \sin\theta)}$$

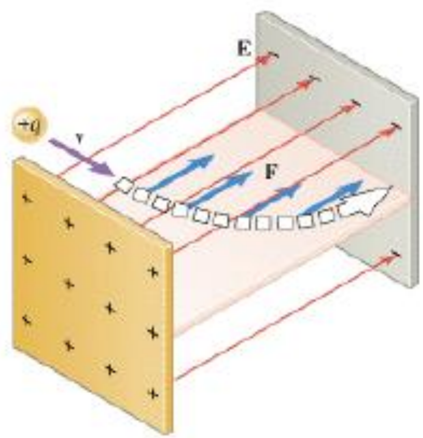
where F is the magnitude of the magnetic force on a positive test charge q_0 , v is the velocity of the charge which makes an angle θ with the direction of the magnetic field.

- **SI Unit of Magnetic Field:** $\frac{\text{newton}\cdot\text{second}}{\text{coulomb}\cdot\text{meter}} = 1\,\text{tesla}(\text{T})$

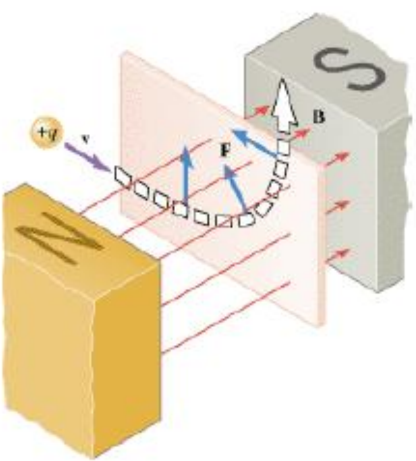
$$1\,\text{gauss} = 10^{-4}\,\text{tesla}$$

Differences of ELECTRIC AND MAGNETIC FIELDS

1. **Direction of forces**
   - **The electric force on a charged particle (both moving and stationary) is always parallel (or anti-parallel) to the electric field direction.**
   - **The magnetic force on a moving charged particle is always perpendicular to both magnetic field and velocity of the particle. No magnetic force on a stationary charged particle.**



(a)

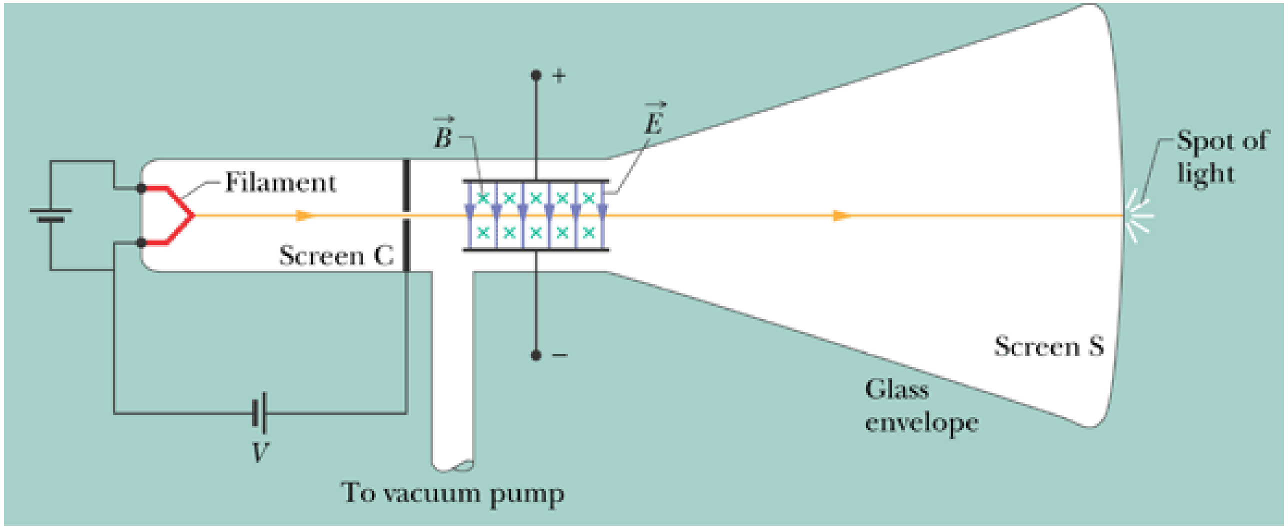


(b)

2. THE WORK DONE ON A CHARGED PARTICLE:

- The electric force can do work on the particle.
- The magnetic force cannot do work and change the kinetic energy of the charged particle.

Crossed Fields: Discovery of the Electron

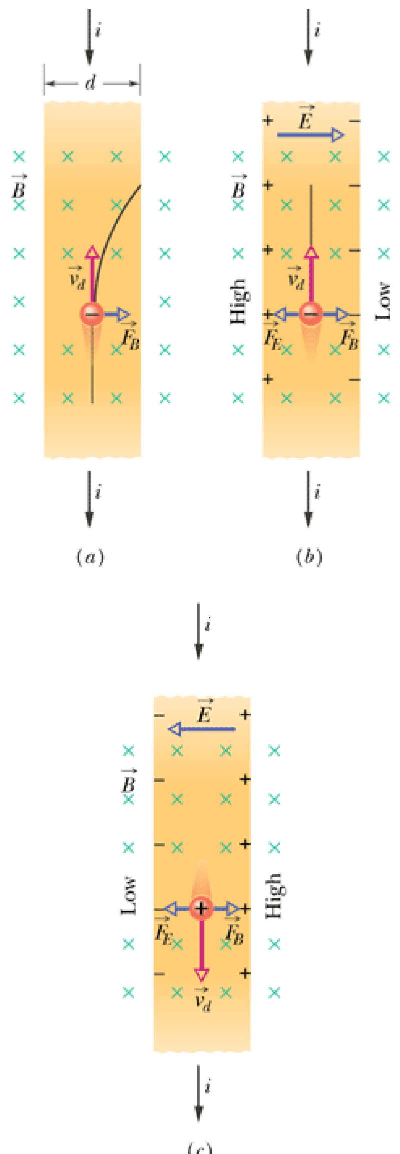


$$\frac{m}{|q|} = \frac{B^2L^2}{2yE},$$

1. Set $\vec{E}$ and $\vec{B}$ to zero and note the position of the spot on screen S due to the undeflected beam.
2. Turn on $\vec{E}$ and measure the resulting beam deflection y.
3. Maintaining $\vec{E}$, now turn on $\vec{B}$ and adjust its value until the beam returns to the undeflected position. (With the forces in opposition, they can be made to cancel.)

Crossed Fields: The Hall Effect

Can the drifting conduction electrons in a copper wire also be deflected by a magnetic field?



the magnitude of that potential difference is

$$V = Ed\ .$$

When the electric and magnetic forces are in balance

$$eE = ev_d B\ . \qquad E = v_d B$$

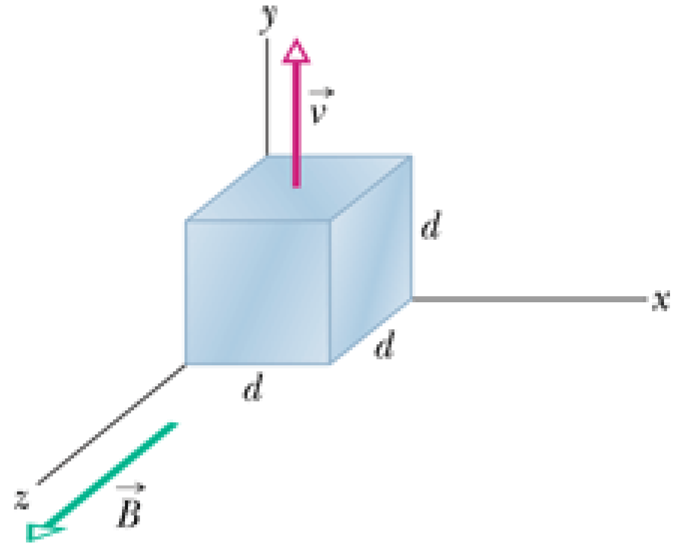
$$v_d = \frac{J}{ne} = \frac{i}{neA}, \qquad A = ld$$

$$\frac{V}{d} = \frac{i}{neld} B \qquad n = \frac{Bi}{Vle},$$

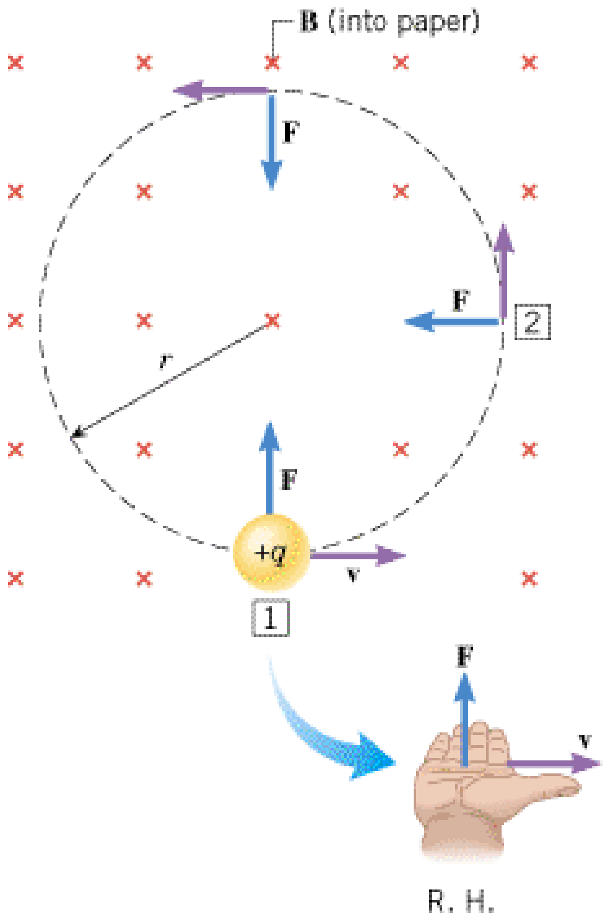
Sample Problem 28

Figure 28-9 shows a solid metal cube, of edge length d=1.5cm, moving in the positive *y* direction at a constant velocity of magnitude 4.0 m/s. The cube moves through a uniform magnetic field of magnitude 0.050 T in the positive *z* direction.

- (a) Which cube face is at a lower electric potential and which is at a higher electric potential because of the motion through the field?
- (b) What is the potential difference between the faces of higher and lower electric potential?



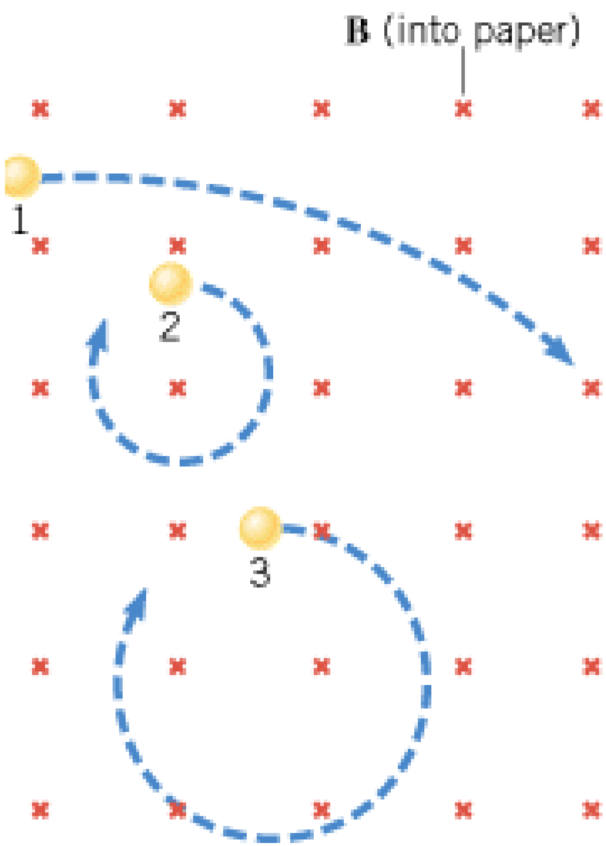
The motion of a charged particle in a constant magnetic field



- A charged particle in a constant magnetic field will do uniform circular motion
- The radius of the circle is

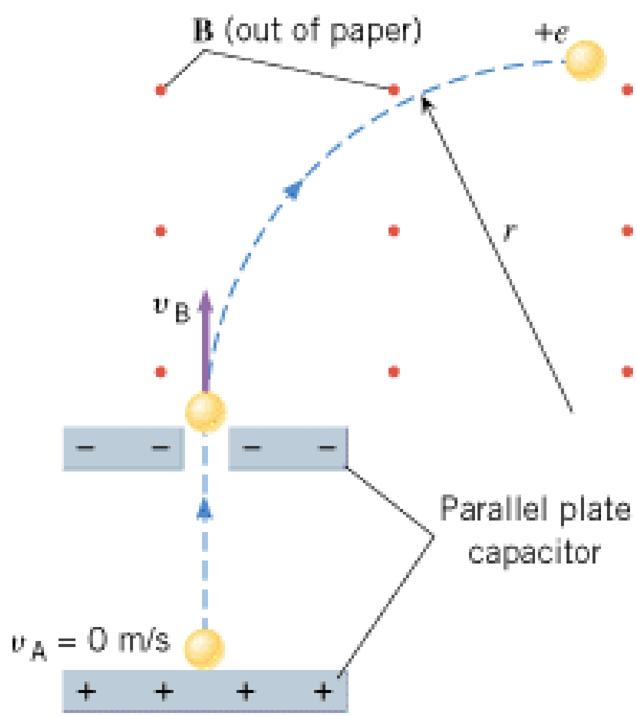
$$r = \frac{mv}{qB}$$

Check Your Understanding



Three particles have identical charges and masses. They enter a constant magnetic field and follow the paths shown in the drawing. Rank the speeds of the particles, largest to smallest.

Example 3 The Motion of a Proton

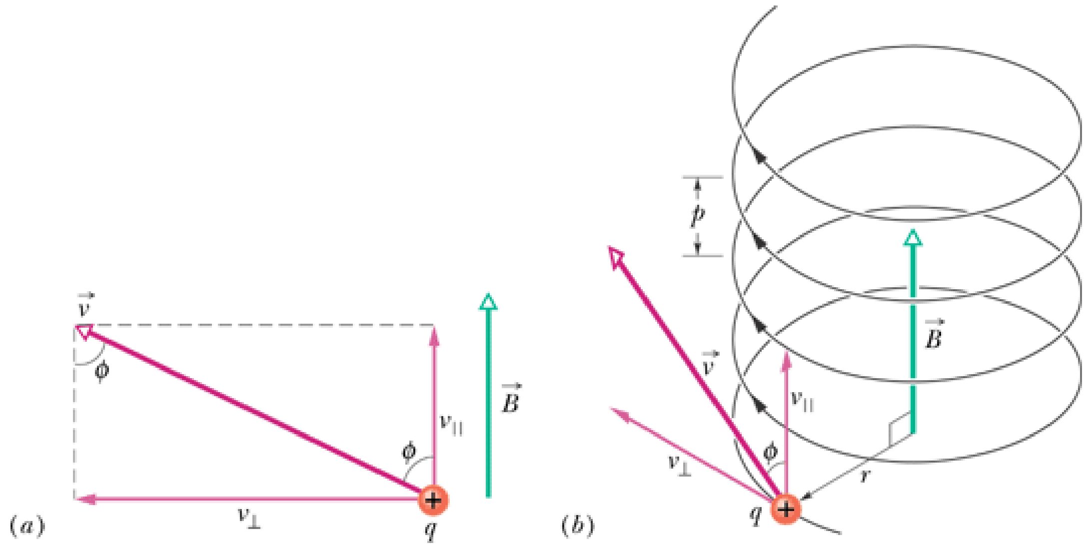


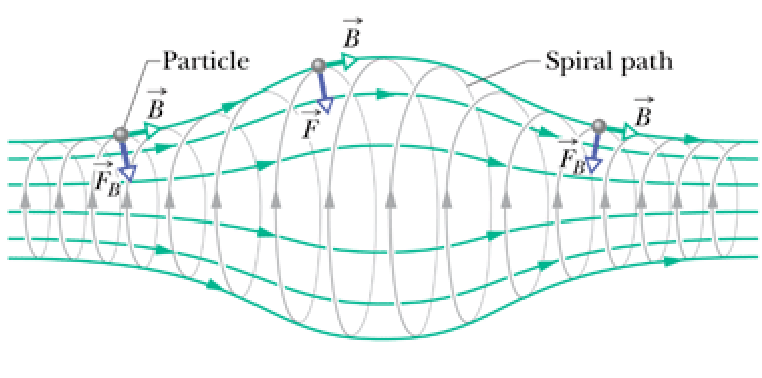
A proton is released from rest at point *A*, which is located next to the positive plate of a parallel plate capacitor (see Figure 21.13). The proton then accelerates toward the negative plate, leaving the capacitor at point *B* through a small hole in the plate. The electric potential of the positive plate is 2100 V greater than that of the negative plate, so $V_A - V_B = 2100$ V. Once outside the capacitor, the proton travels at a constant velocity until it enters a region of constant magnetic field of magnitude 0.10 T. The velocity is perpendicular to the magnetic field, which is directed out of the page in Figure 21.13. Find (a) the speed v_B of the proton when it leaves the negative plate of the capacitor, and (b) the radius *r* of the circular path on which the proton moves in the magnetic field.

Helical Paths

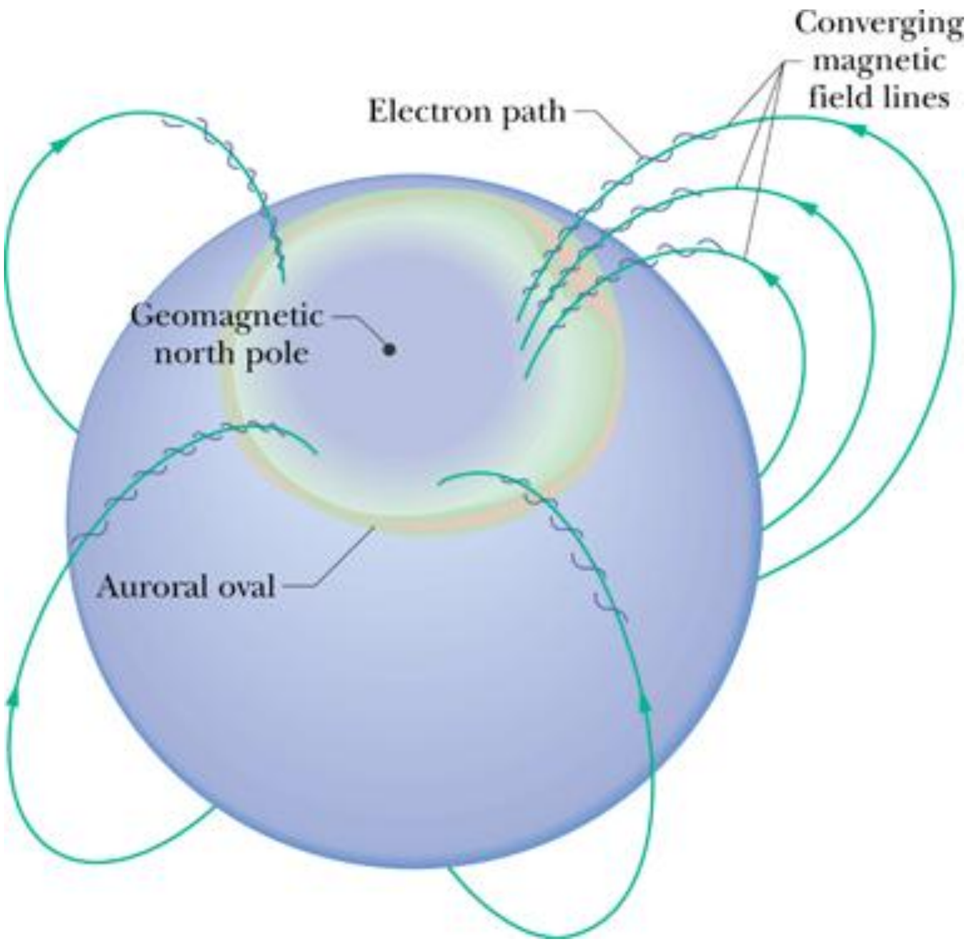
If the velocity $\vec{v}$ of a charged particle has a component parallel to the (uniform) magnetic field $\vec{B}$, the particle will move in a helical path about the direction of the field vector.

$$v_{||} = v\cos\phi \quad \text{and} \quad v_{\perp} = v\sin\phi \, .$$





The Auroral


Converging magnetic field lines
Electron path
Geomagnetic north pole
Auroral oval

The Cyclotron