Answer to Essential Question 19.2: Try this – walk in a straight line while whirling your hand in a circle around an axis parallel to your velocity. Your hand traces out a spiral, the shape of the path followed by the particle. For the particle, the spiral's axis is parallel to the magnetic field.

19-3 Using the Right-hand Rule

Let's practice using the right-hand rule (described at the end of section 19-2).

EXAMPLE 19.3 – Applying the right-hand rule
Draw a picture of each situation below, and use the picture to help answer the question.
(a) In what direction is the magnetic force on a particle that has a positive charge, and which has a velocity directed to the right in a uniform magnetic field directed up the page?
(b) In what direction is the magnetic force on a negatively charged particle, and which has a velocity directed down the page in a uniform magnetic field that has one component directed out of the page, and the other component directed down the page?
(c) In what direction is the velocity of a particle that has a positive charge, and which experiences a magnetic force directed into the page in a uniform magnetic field directed right?

SOLUTION
(a) Consider Figure 19.8. The magnetic force is perpendicular to the plane defined by the velocity and the magnetic field, which is the plane of the page. Thus, the force is either directed into or out of the page. Our right hands can distinguish between these directions. Place your right hand on the page, with the fingers pointing right. If the plane of the hand is perpendicular to the page, with the thumb sticking up out of the page, we can curl the fingers into the direction of the field. Thus, the force on the positive charge is out of the page.
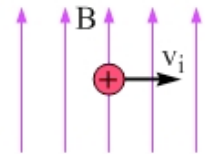

Figure 19.8: A positively charged particle is directed right, in a field directed up.

(b) This situation is shown in Figure 19.9. A magnetic field that is parallel to the particle's velocity exerts no force. Thus, we can focus on the perpendicular component of the field. Place your right hand flat on the page with the palm up and the fingers directed to the bottom of the page, so you can curl the fingers up, out of the page. The thumb points to the left, in the direction of the force on a positive charge. Our charge is negative, so the right hand lies to us and the force is directed to the right.
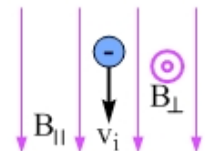

Figure 19.9: A negatively charged particle is moving down, in a field directed both down the page, parallel to the velocity, ($B_{\parallel}$) and out of the page ($B_{\perp}$), perpendicular to the velocity.

(c) Consider the situation shown in Figure 19.10. First, remember that the velocity is perpendicular to the force, so, if the force is perpendicular to the page, the velocity must be in the plane of the page. Let's apply the right-hand rule in reverse order. Curl the fingers of your right hand, and hold your hand with the thumb pointing down, into the page, and with your curled fingers directed right. When you un-curl your fingers 90°, they point up the page in the direction of the velocity component that is perpendicular to the magnetic field. However, there may or may not be a velocity component directed left or right, parallel to the magnetic field lines. This case is ambiguous – we can't say for certain which direction the velocity is in because the angle between $\vec{v}$ and $\vec{B}$ does not have to be 90°.
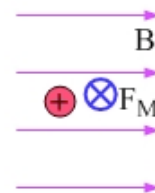

Related End-of-Chapter Exercises: 13 – 16.

Figure 19.10: A moving positively charged particle experiences a force directed into the page, in a field directed right.

A special case: a charged particle with a velocity perpendicular to the magnetic field

When the velocity of a charged particle is perpendicular to the field, the particle follows a circular path. Applying the form of Newton's second law for circular motion, $\sum F = mv^2/r$:

$$qvB\sin\theta = \frac{mv^2}{r}.$$

The velocity and magnetic field are perpendicular, so we have $\sin(90°) = 1$. Solving for r:

$$r = \frac{mv}{qB}.$$ (Equation 19.3: **Radius of the path, when $\vec{v}$ and $\vec{B}$ are perpendicular**)

We can find the time it takes the particle to go around the circle once, which we call the period of the orbit, by dividing the circumference of the orbit by the particle's speed:

$$T = \frac{2\pi r}{v} = \frac{2\pi mv}{vqB} = \frac{2\pi m}{qB}.$$ (Equation 19.4: **The period of the circular orbit**)

Note that *the period is independent of the speed* of the particle.

EXPLORATION 19.3 – Identifying the particles

As shown in Figure 19.11, four particles pass through a square region of uniform magnetic field directed perpendicular to the page.

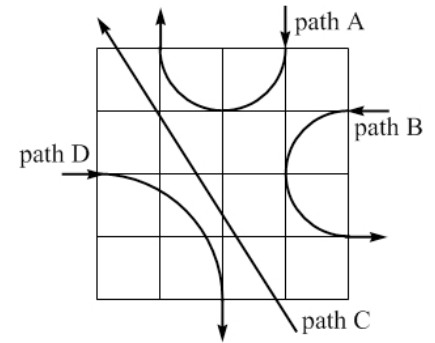| Particle	Charge	Mass	Speed	Path taken
1	0	$2m$	$6v$	
2	$+q$	m	$4v$	
3	$+2q$	$4m$	v	
4	$-q$		$2v$	

Table 19.2: The charge, mass, and speed for four particles passing through a magnetic field.

Figure 19.11: The paths followed by the particles.

Step 1 – *Identify the path taken by particle 1.* Because particle 1 has no charge, the field exerts no force on it. Particle 1 travels through the field in a straight line – so, it follows path C.

Step 2 – *Are the paths clockwise or counterclockwise? Use your answer to determine the direction of the magnetic field.* Positive charges travel in one sense, while negative charges travel in the opposite sense. Paths A and D both show clockwise motion, so these are the paths taken by the two positive charges. Path B shows a counterclockwise motion, so path B is taken by particle 4, the only particle with a negative charge. Applying the right-hand rule to the positive particle traveling along path D, we find that the magnetic field is directed out of the page.

Step 3 – *Apply Equation 19.3 to see which particle follows path A and which follows path D.* Equation 19.3 tells us that the radius of the path is proportional to the mass multiplied by speed divided by the charge (we neglect the factor of the magnetic field, which is the same for all the charges). This combination is $4mv/q$ for particle 2, and $2mv/q$ for particle 3. Thus, the path followed by particle 2 has twice the radius (path D) as that followed by particle 3 (path A).

Key idea: The radius of curvature, and the direction of curvature, provides information about the speed, charge, and/or the mass of a particle. **Related End-of-Chapter Exercises: 7, 8, 17, 18.**

Essential Question 19.3: Rank the four particles in Exploration 19.3 in terms of the magnitude of the force applied to them by the magnetic field, from largest to smallest.