Answer to Essential Question 5.4: Yes. An object has an acceleration whenever its velocity changes. Although the magnitude of the velocity is constant, the direction of the velocity changes, so there must be an acceleration. We'll investigate this further in the next section.

5-5 Uniform Circular Motion

Uniform circular motion is motion in a circle with constant speed. Let's define *T*, the period of the uniform circular motion, to be the time it takes an object to travel around one complete circle. Because the speed is constant, we can relate the speed to the distance traveled very simply: v = distance/time = $2\pi r / T$.

As with straight-line motion, the magnitude of the acceleration is related to the speed the same way that the speed is related to the distance: $a = 2\pi v / T$.

If we combine the two equations above, we get what's called the *centripetal acceleration*.

When an object is traveling in a circular path, the object has an acceleration directed toward the center of the circle. This acceleration is known as the centripetal acceleration :

$$a_c = \frac{v^2}{r} .$$ (Equation 5.3: **Centripetal acceleration**)

The direction of the centripetal acceleration is toward the center of the circle, because the change in velocity is toward the center, as illustrated in Figure 5.10.

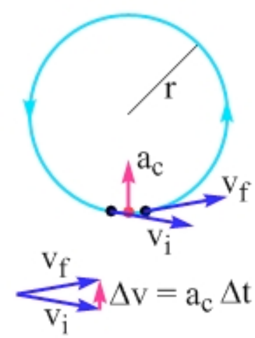


Figure 5.10: Subtracting the velocity just before the object is at the bottom of the circle ($\vec{v}_i$) from the velocity just after that point ($\vec{v}_f$) gives the change in velocity $\Delta\vec{v}$, which is directed toward the center of the circle. The centripetal acceleration is proportional to this change in velocity and thus is also directed toward the center.

Many people have heard the term "centripetal force." Is this a new force that arises because something goes in a circle? No, it is not. Let's investigate this idea. Which free-body diagram in Figure 5.11 correctly shows the force(s) acting on the Earth (E) as it orbits the Sun, when the Earth is at the position shown, to the right of the Sun? F_G is the gravitational force exerted on the Earth by the Sun, while F_C stands for centripetal force.

The correct free-body diagram is diagram 3, which shows only the force of gravity applied by the Sun on the Earth. The word "centripetal" means "directed toward the center." When an object experiences uniform circular motion, the object has a centripetal acceleration directed toward the center of the circle. The centripetal acceleration requires a net force directed toward the center, but this net force comes from one or more real forces (such as gravity, tension, or friction) or their components. There is no magical new centripetal force responsible for this motion. Thus, we will avoid the term "centripetal force" altogether, and talk about the force, or forces, responsible for the centripetal acceleration, instead.

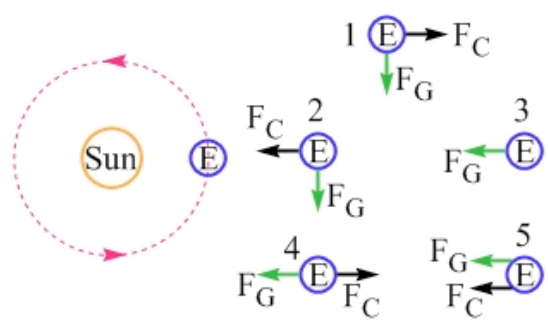


Figure 5.11: Five possible free-body diagrams for the Earth (E), as it orbits the Sun.

Figure 5.12: To avoid confusion, we will avoid the term “centripetal force” and we will not to draw a centripetal force on a free-body diagram.

EXPLORATION 5.5 – Identifying the force(s) responsible for the centripetal acceleration

Which force gives rise to the centripetal acceleration in the following situations?

Step 1 - ***While you are riding your bike, you turn a corner, following a circular arc. What is the force acting on your bike that is associated with the centripetal acceleration, keeping you going in a circle?***

Let’s sketch a free-body diagram (see Figure 5.14). As usual, there is a downward force of gravity acting on the system consisting of you and the bike, balanced by an upward normal force applied by the road. If there is no friction acting on the bike tires, the bike would keep going in a straight line, moving away from the center of the circle. The force of friction acting on the bike tires is the force pointing toward the center of the circular arc, opposing the tendency for the bike to move out from the center of the circle. As long as the tires do not skid on the road surface, the friction force is a static force of friction.

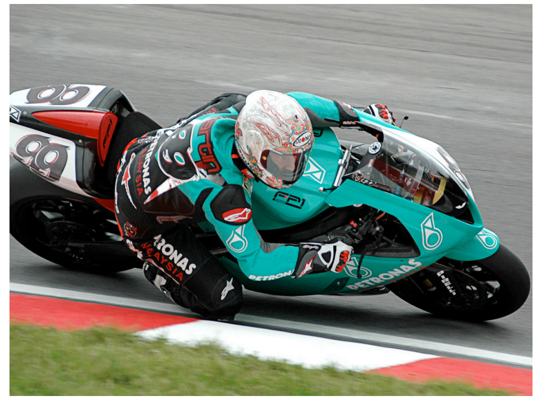
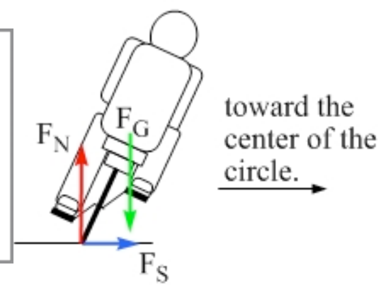


Figure 5.13: A photograph of motorcycle racer Steve Martin rounding a bend. Which force is directed in toward the center of the circular arc as the motorcycle rounds the bend? Photo credit: John Edwards, via http://www.publicdomainpictures.net.

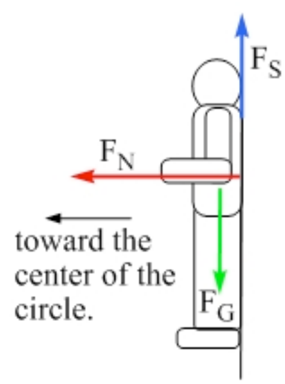
Figure 5.14: A free-body diagram for a rider-bike system while the rider is traveling around a curve.



Step 2 - ***On a carnival ride called the Rotor, shown in the opening photo of this chapter, once the ride is spinning quickly, the riders are pinned to the wall and the floor is removed from under them. Which force is directed toward the center of the circle?***

Let’s sketch the free-body diagram of a person on the moving ride. As usual, the force of gravity is acting down. The person’s velocity tries to carry them farther from the center of the circle, but the wall gets in the way. There is a contact force associated with the person-wall interaction. The wall exerts a normal force, directed toward the center of the circle, on the person. This is the force we’re looking for. The complete free-body diagram, in Figure 5.15, also shows an upward force of friction opposing the force of gravity. This force of friction is static friction because there is no relative motion between the person and the wall.

Figure 5.15: A free-body diagram for a person on the Rotor.



Key ideas for circular motion: In uniform circular motion, there is a net force directed toward the center of the circle. We do not need to invent a magical new force to act as the net force. Instead, this net force toward the center of the circle is associated with one or more of the standard forces we already know about. **Related End-of-Chapter Exercises 11, 59.**

Essential Question 5.5: Why does the Rotor have to be spinning fast before the floor is removed?