UNIVERSITY PHYSICS

Chapter 11 ANGULAR MOMENTUM

PowerPoint Image Slideshow

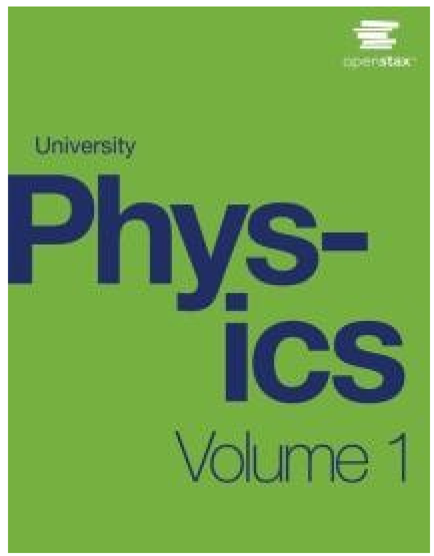


FIGURE 11.1

A helicopter has its main lift blades rotating to keep the aircraft airborne. Due to conservation of angular momentum, the body of the helicopter would want to rotate in the opposite sense to the blades, if it were not for the small rotor on the tail of the aircraft, which provides thrust to stabilize it.

Wheels and rolling

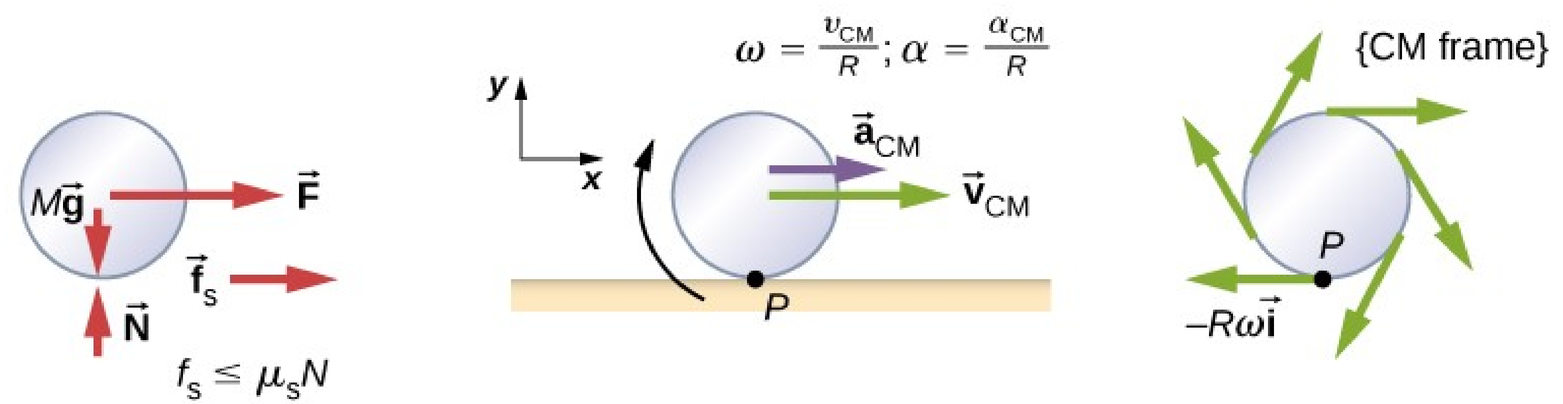
FIGURE 11.2

(a) (b)

a) The bicycle moves forward, and its tires do not slip. The bottom of the slightly deformed tire is at rest with respect to the road surface for a measurable amount of time.

b) This image shows that the top of a rolling wheel appears blurred by its motion, but the bottom of the wheel is instantaneously at rest. (credit a: modification of work by Nelson Lourenço; credit b: modification of work by Colin Rose)

FIGURE 11.3



(a) Forces on the wheel

(b) Wheel rolls without slipping

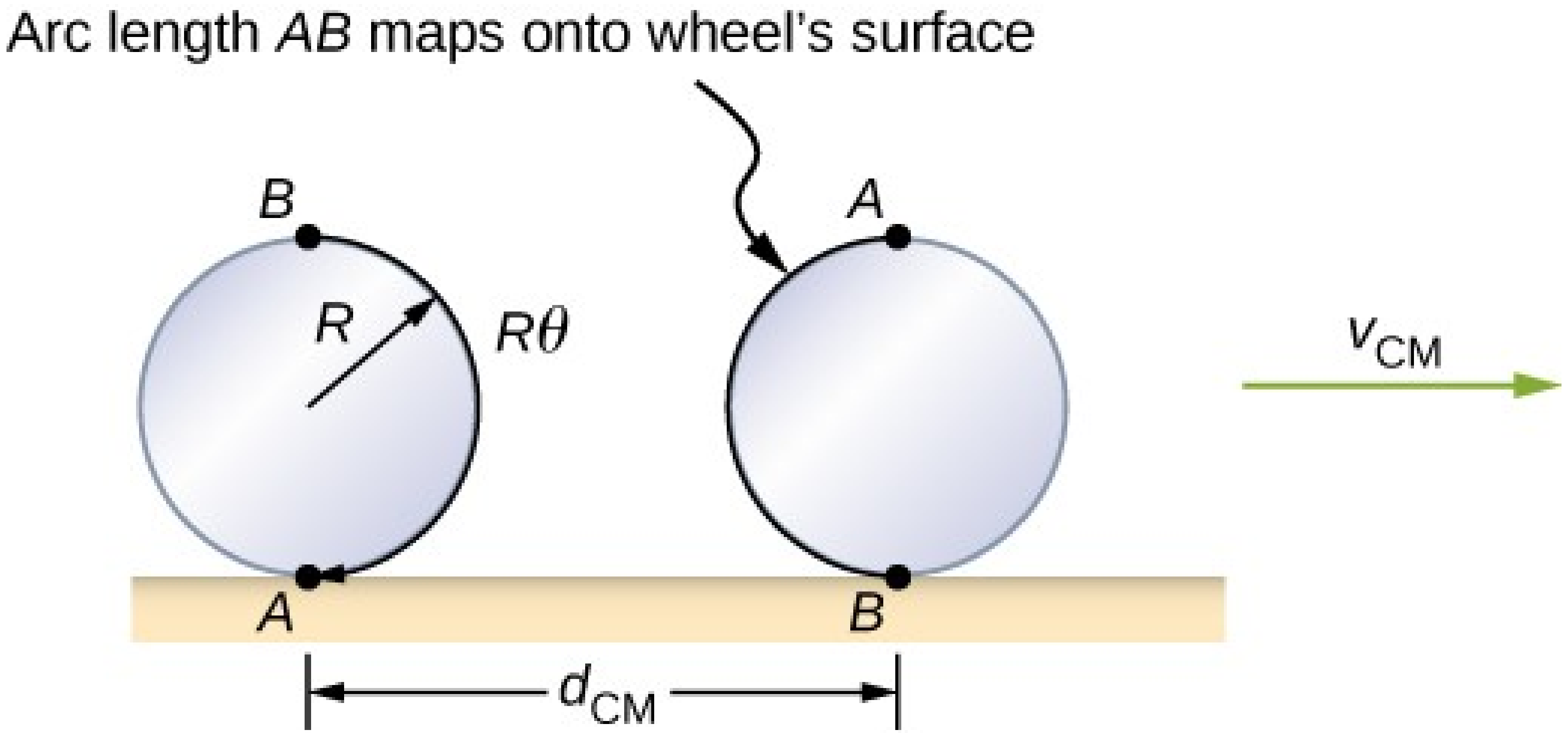
(c) Point *P* has velocity vector in the negative direction with respect to the center of mass of the wheel

a) A wheel is pulled across a horizontal surface by a force . The force of static friction , is large enough to keep it from slipping.

b) The linear velocity and acceleration vectors of the center of mass and the relevant expressions for and . Point *P* is at rest relative to the surface.

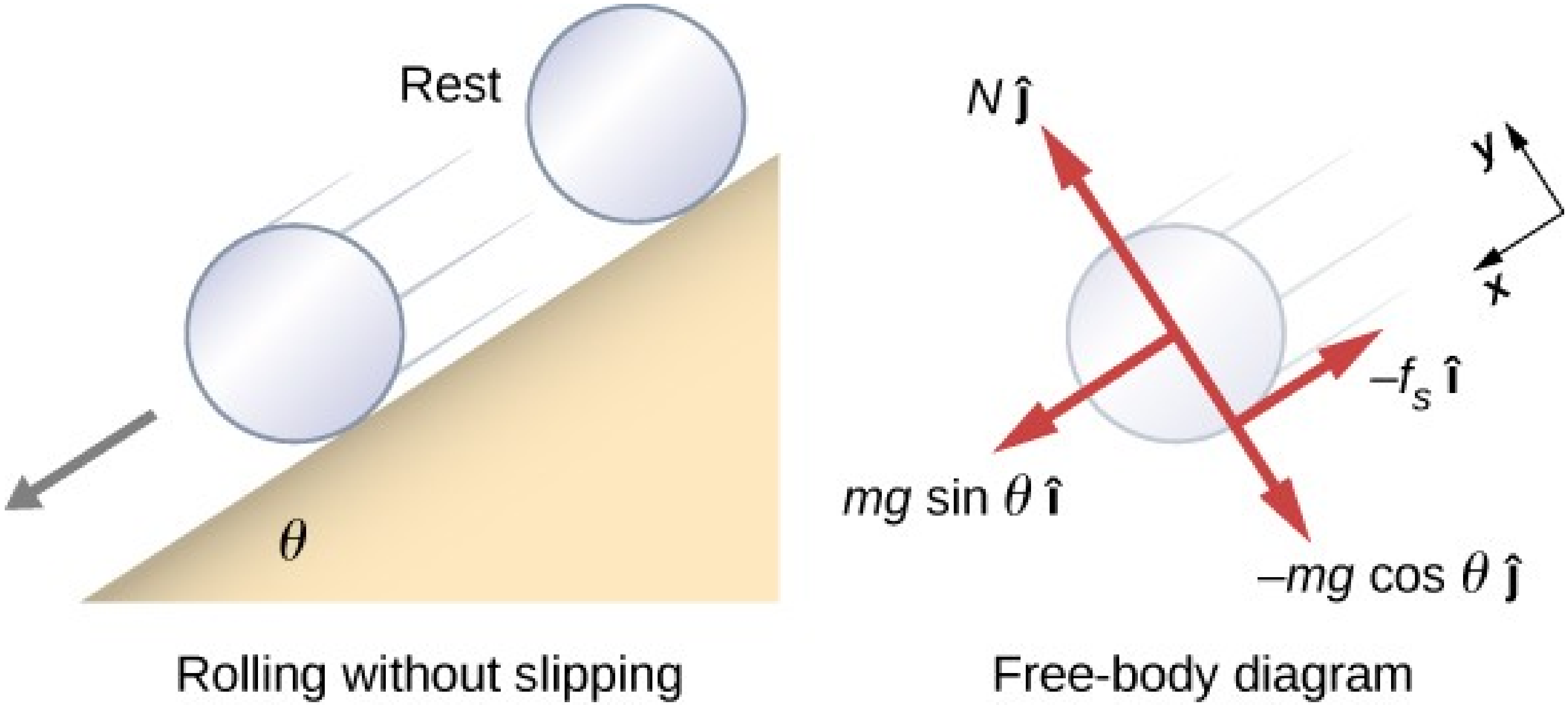
c) Relative to the center of mass (CM) frame, point *P* has linear velocity .

FIGURE 11.4



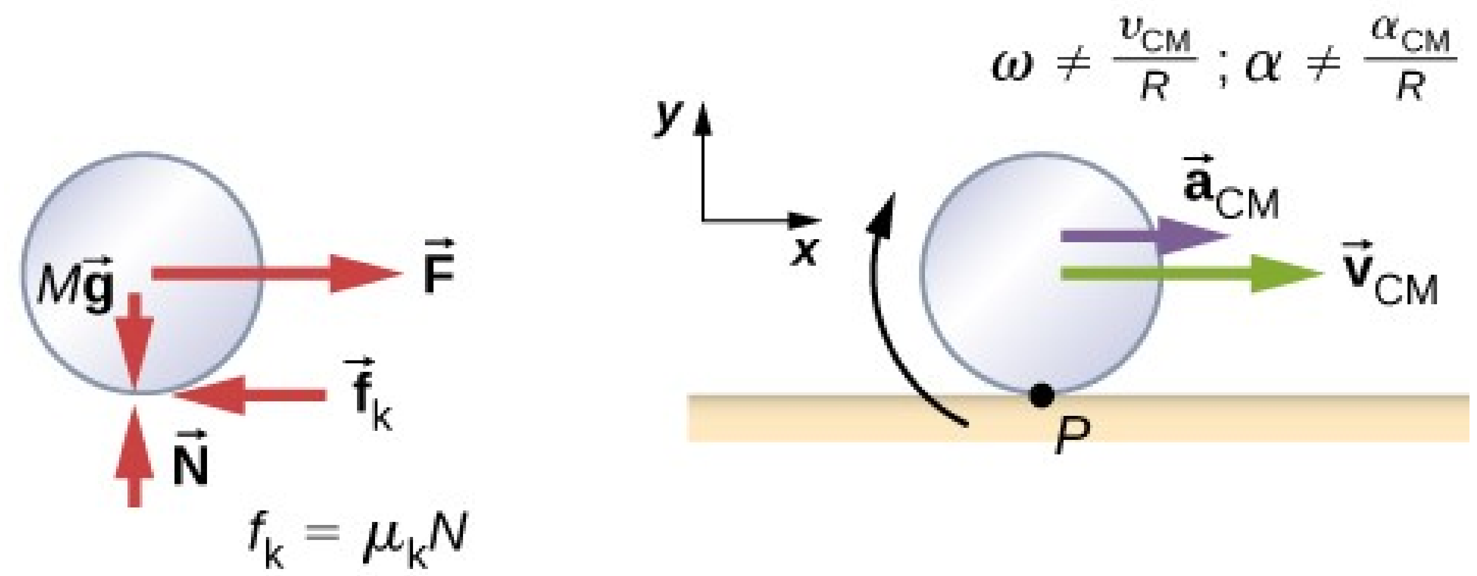
As the wheel rolls on the surface, the arc length $R\theta$ from A to B maps onto the surface, corresponding to the distance d_{CM} that the center of mass has moved.

FIGURE 11.5



A solid cylinder rolls down an inclined plane without slipping from rest. The coordinate system has *x* in the direction down the inclined plane and *y* perpendicular to the plane. The free-body diagram is shown with the normal force, the static friction force, and the components of the weight . Friction makes the cylinder roll down the plane rather than slip.

FIGURE 11.6



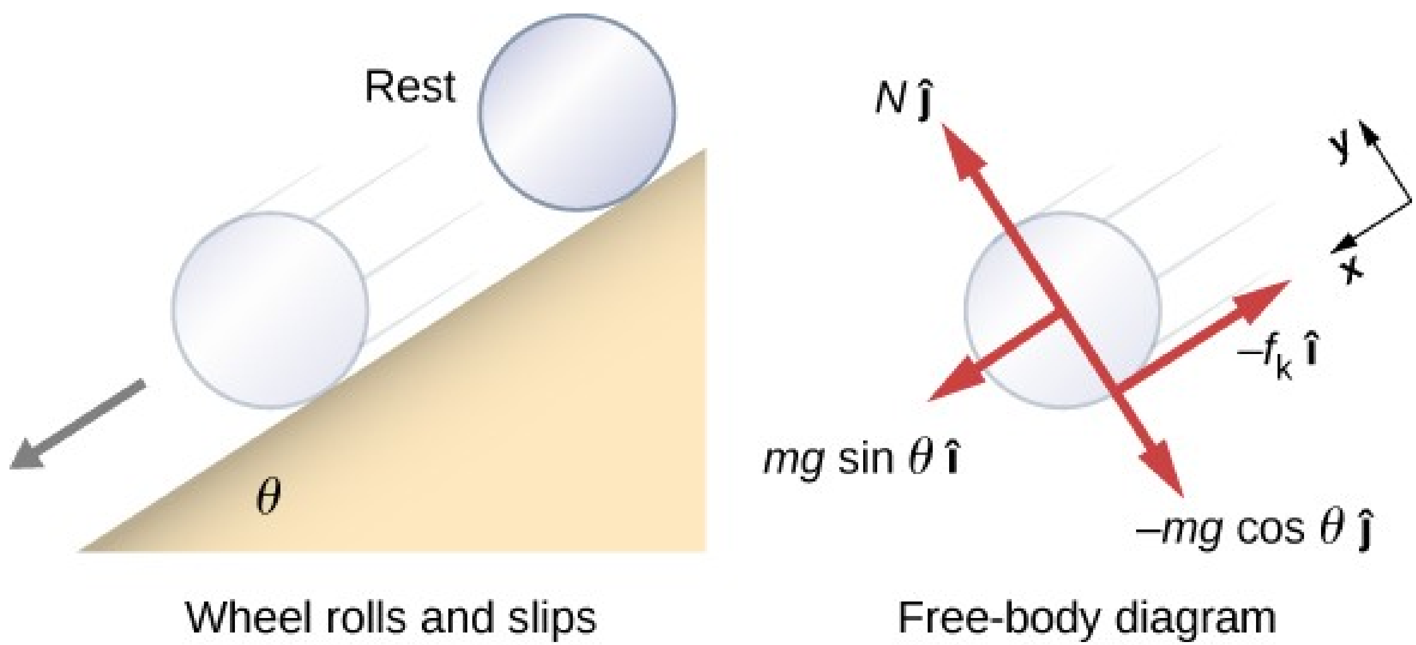
(a) Forces on wheel

(b) Wheel is rolling and slipping

a) Kinetic friction arises between the wheel and the surface because the wheel is slipping.

b) The simple relationships between the linear and angular variables are no longer valid.

FIGURE 11.7

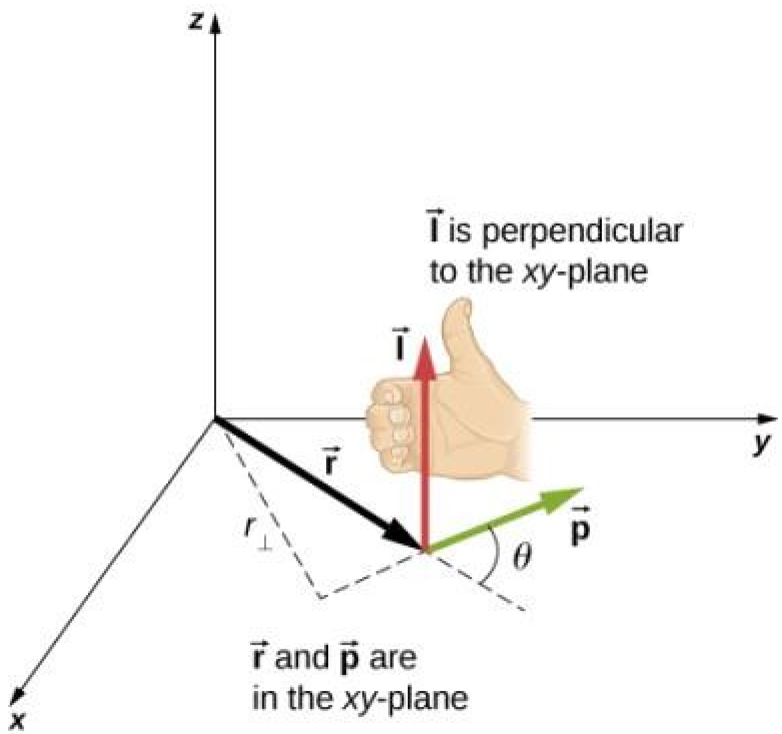


A solid cylinder rolls down an inclined plane from rest and undergoes slipping. The coordinate system has *x* in the direction down the inclined plane and *y* upward perpendicular to the plane. The free-body diagram shows the normal force, kinetic friction force, and the components of the weight .

Angular momentum

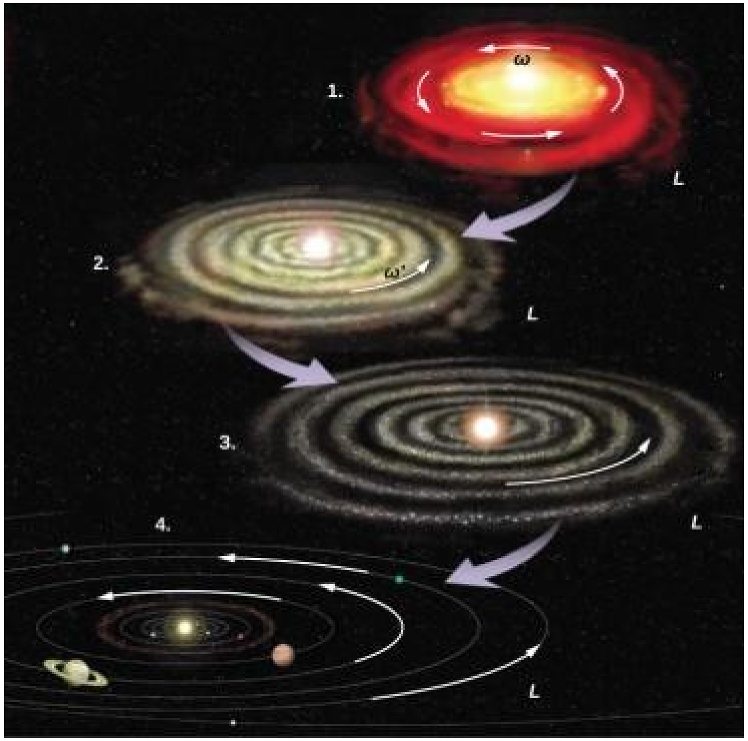
$$\vec{L} = \vec{r} \times \vec{p}$$

FIGURE 11.9



In three-dimensional space, the position vector locates a particle in the *xy*-plane with linear momentum . The angular momentum with respect to the origin is , which is in the *z*-direction. The direction of is given by the right-hand rule, as shown.

FIGURE 11.15



The solar system coalesced from a cloud of gas and dust that was originally rotating. The orbital motions and spins of the planets are in the same direction as the original spin and conserve the angular momentum of the parent cloud. (credit: modification of work by NASA)

EXERCISE 11.2

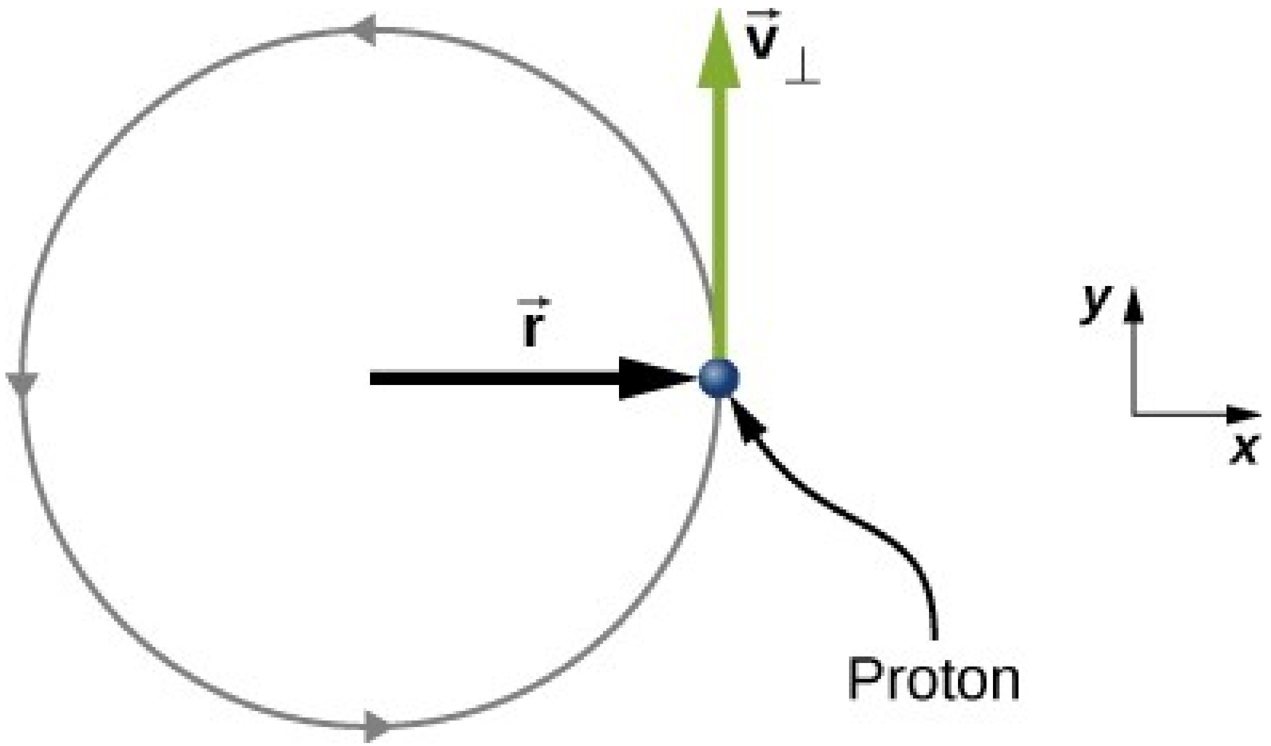
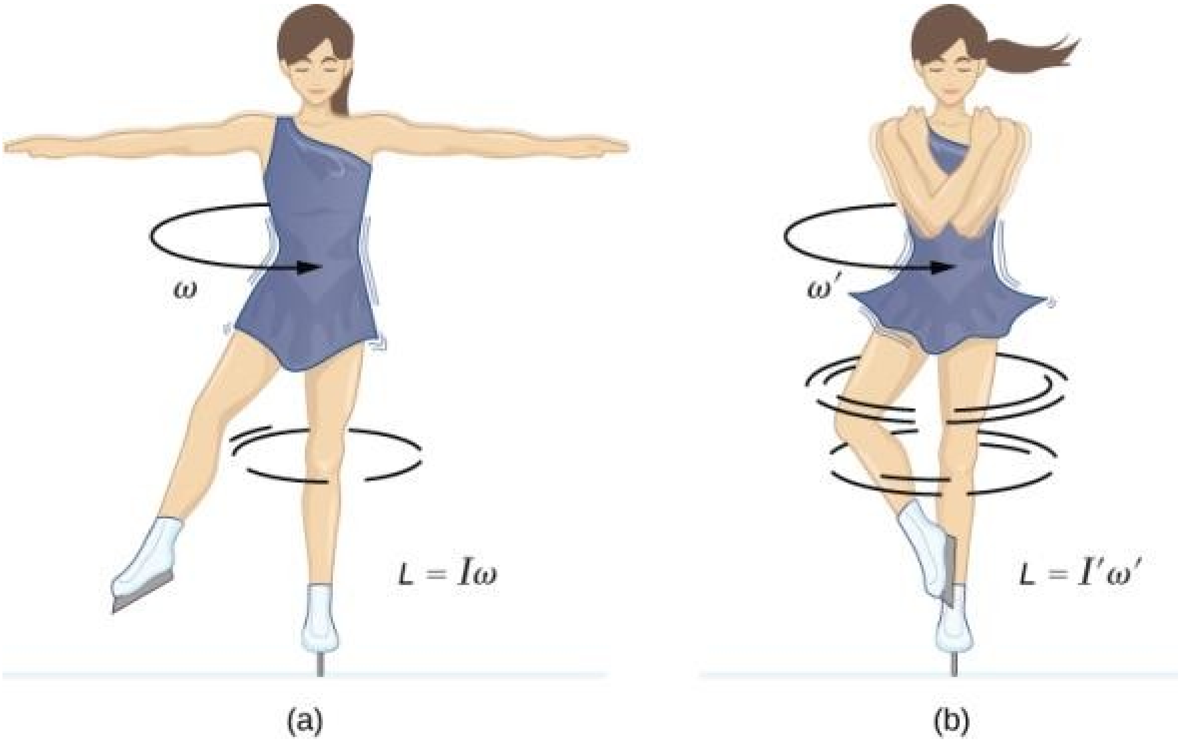


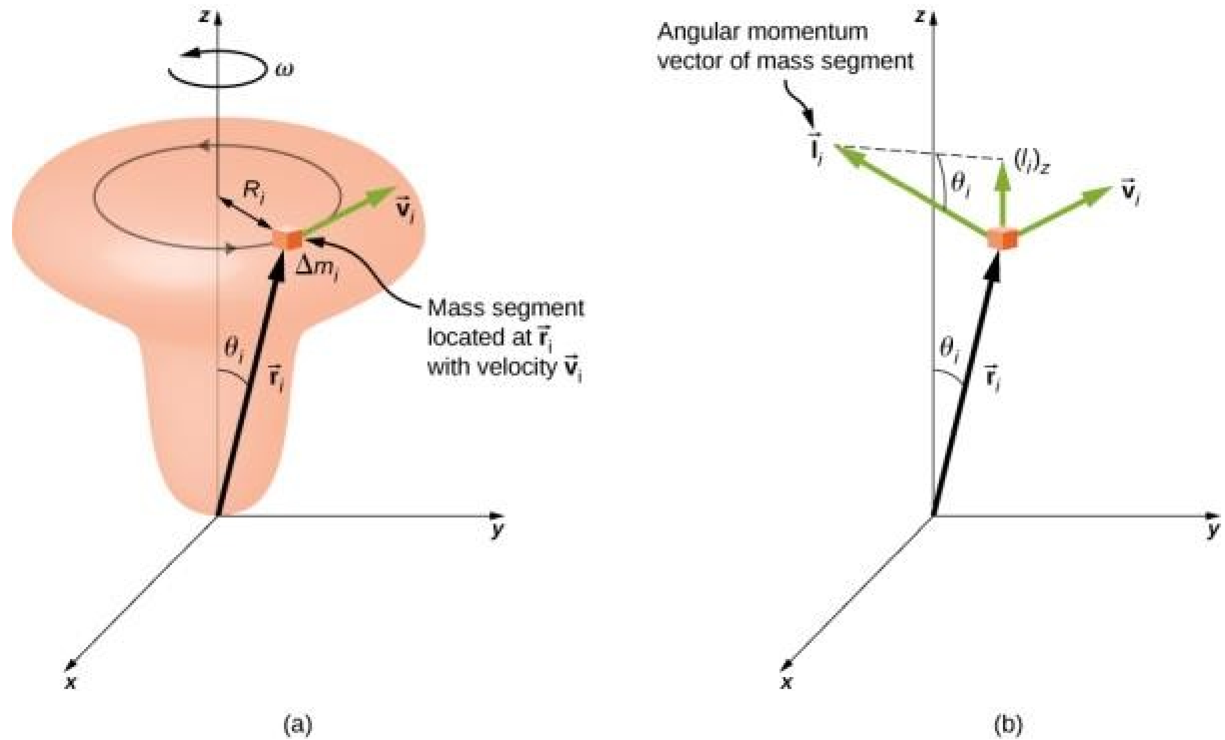
FIGURE 11.14



a) An ice skater is spinning on the tip of her skate with her arms extended. Her angular momentum is conserved because the net torque on her is negligibly small.

b) Her rate of spin increases greatly when she pulls in her arms, decreasing her moment of inertia. The work she does to pull in her arms results in an increase in rotational kinetic energy.

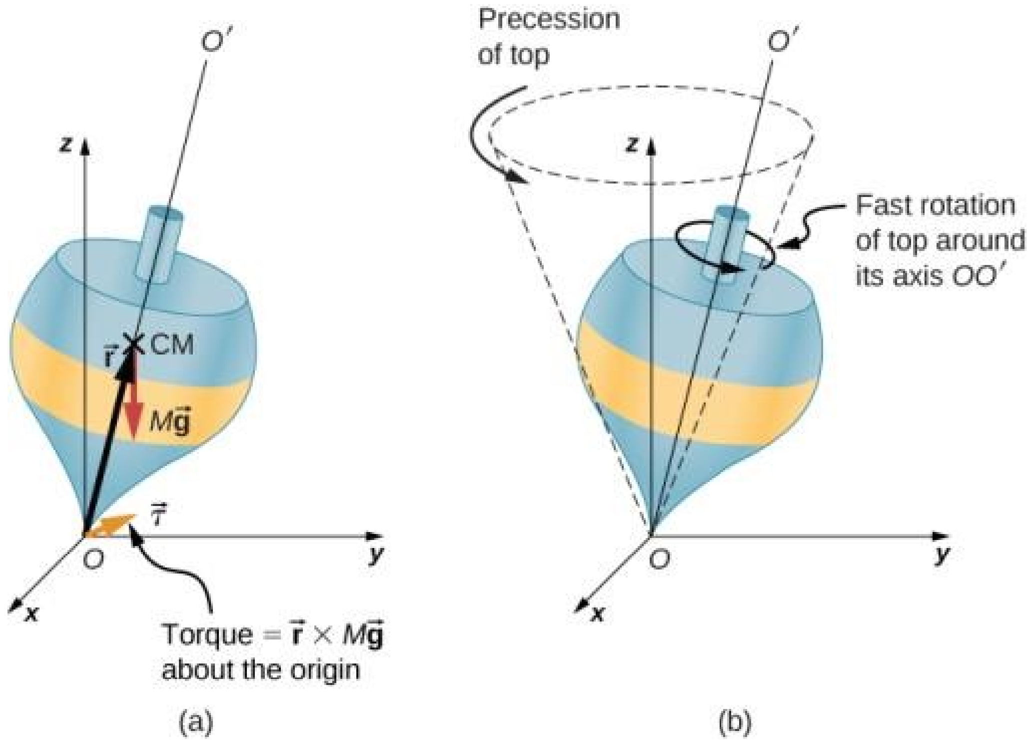
FIGURE 11.12



a) A rigid body is constrained to rotate around the *z*-axis. The rigid body is symmetrical about the *z*-axis. A mass segment is located at position , which makes angle with respect to the *z*-axis. The circular motion of an infinitesimal mass segment is shown.

b) is the angular momentum of the mass segment and has a component along the *z*-axis .

FIGURE 11.20



a) If the top is not spinning, there is a torque about the origin, and the top falls over.

b) If the top is spinning about its axis *OO′*, it doesn't fall over but precesses about the *z*-axis.

FIGURE 11.21

The force of gravity acting on the center of mass produces a torque in the direction perpendicular to . The magnitude of doesn't change but its direction does, and the top precesses about the *z*-axis.

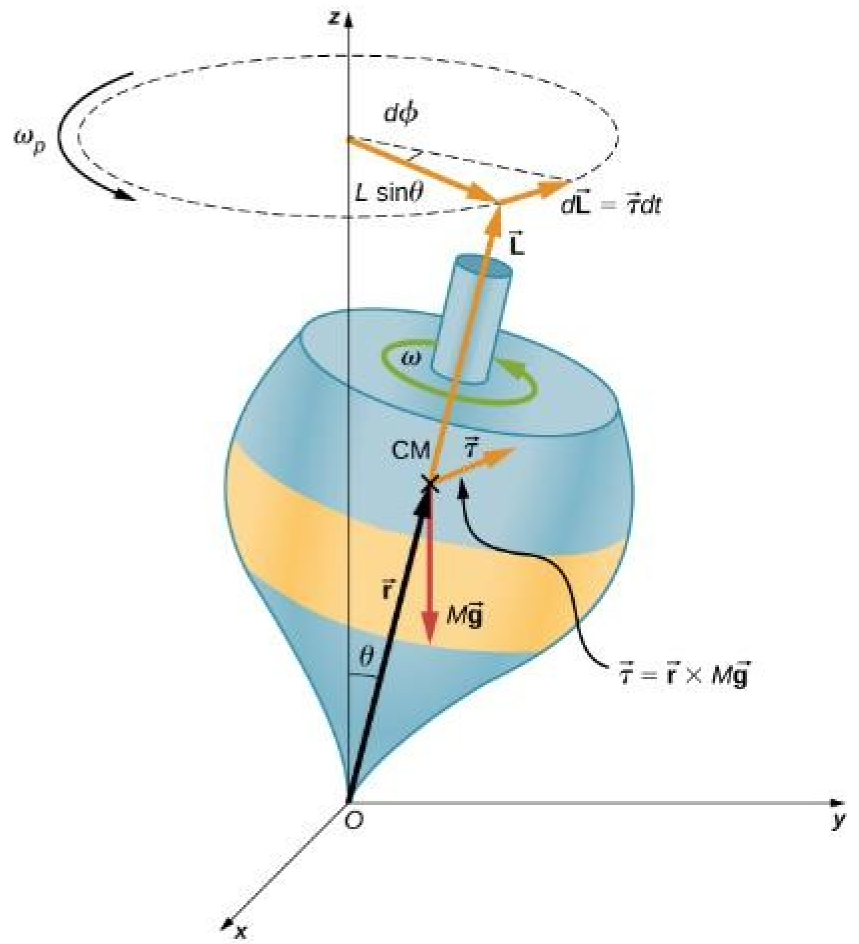
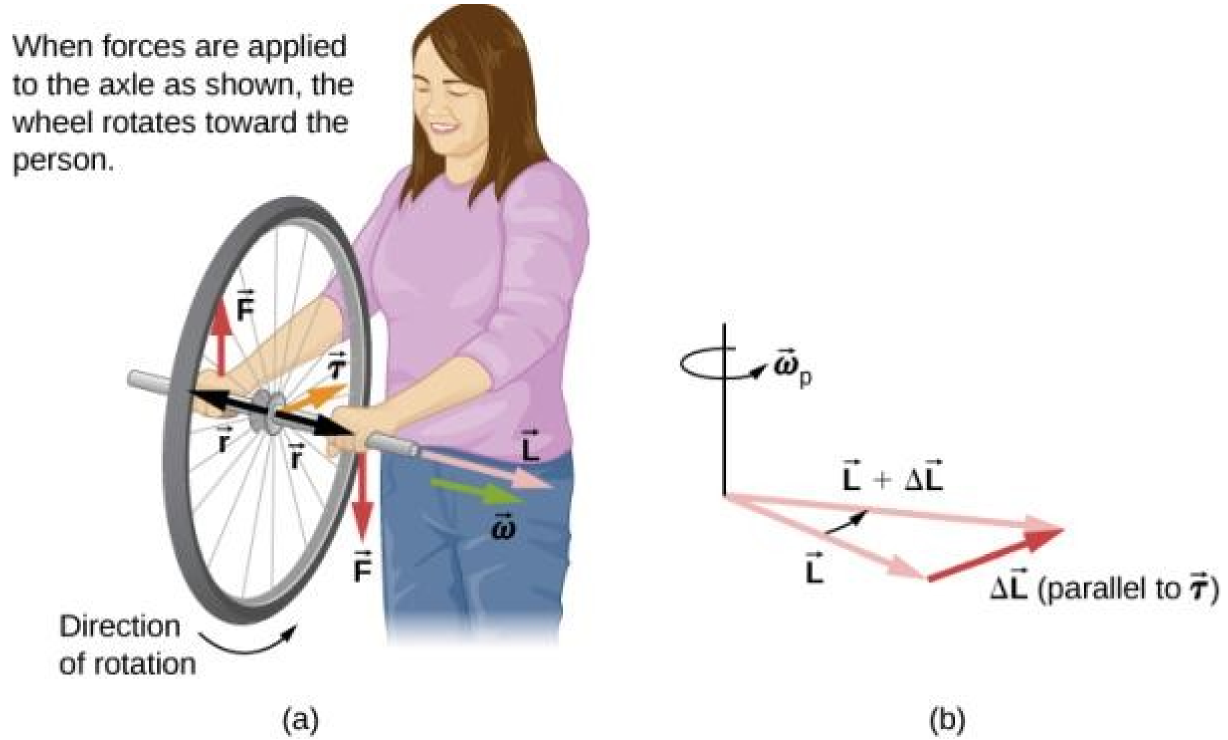


FIGURE 11.22



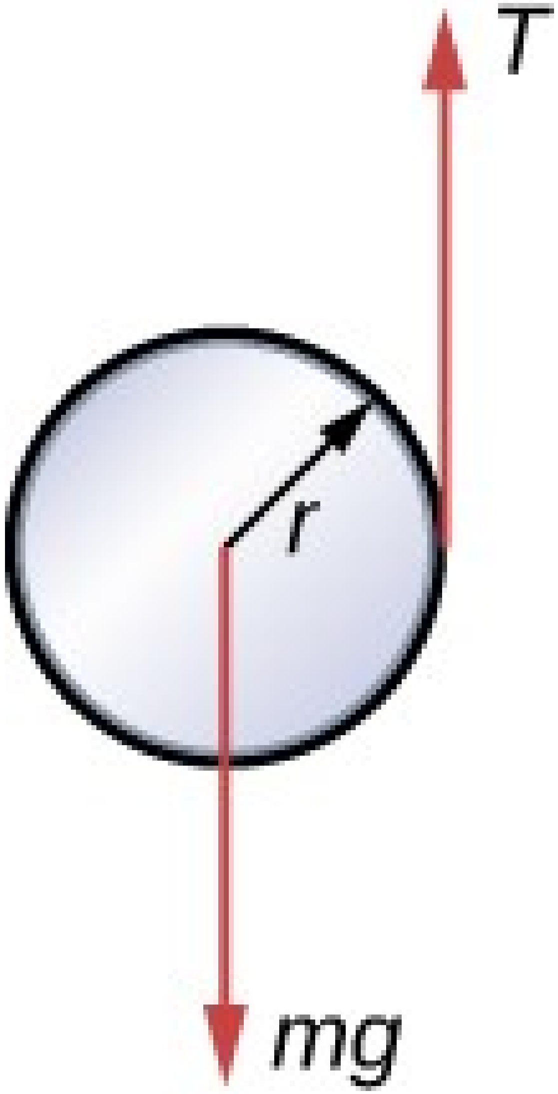
a) A person holding the spinning bike wheel lifts it with her right hand and pushes down with her left hand in an attempt to rotate the wheel. This action creates a torque directly toward her. This torque causes a change in angular momentum in exactly the same direction.

b) A vector diagram depicting how and add, producing a new angular momentum pointing more toward the person. The wheel moves toward the person, perpendicular to the forces she exerts on it.

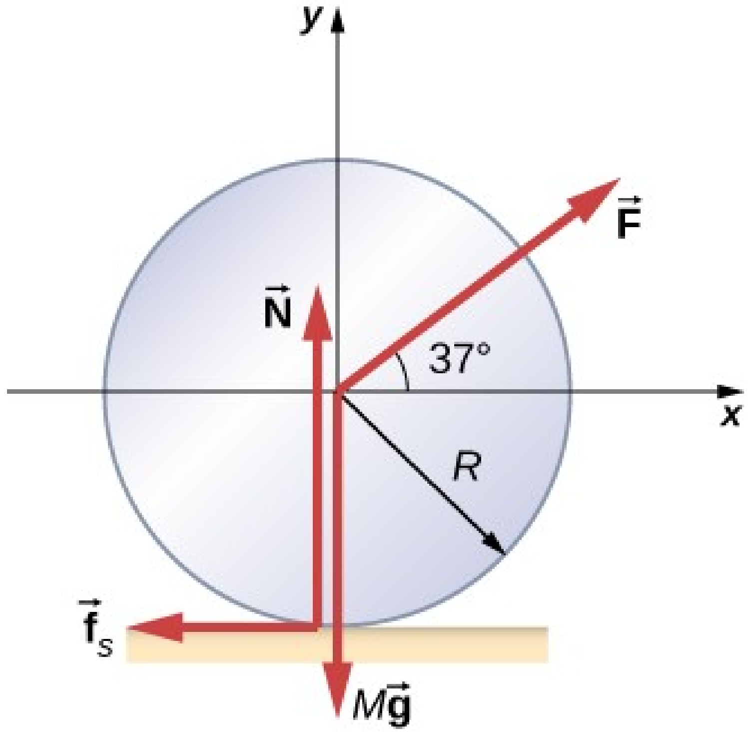
Examples

EXERCISE 26

A yo-yo can be thought of a solid cylinder of mass *m* and radius *r* that has a light string wrapped around its circumference (see below). One end of the string is held fixed in space. If the cylinder falls as the string unwinds without slipping, what is the acceleration of the cylinder?

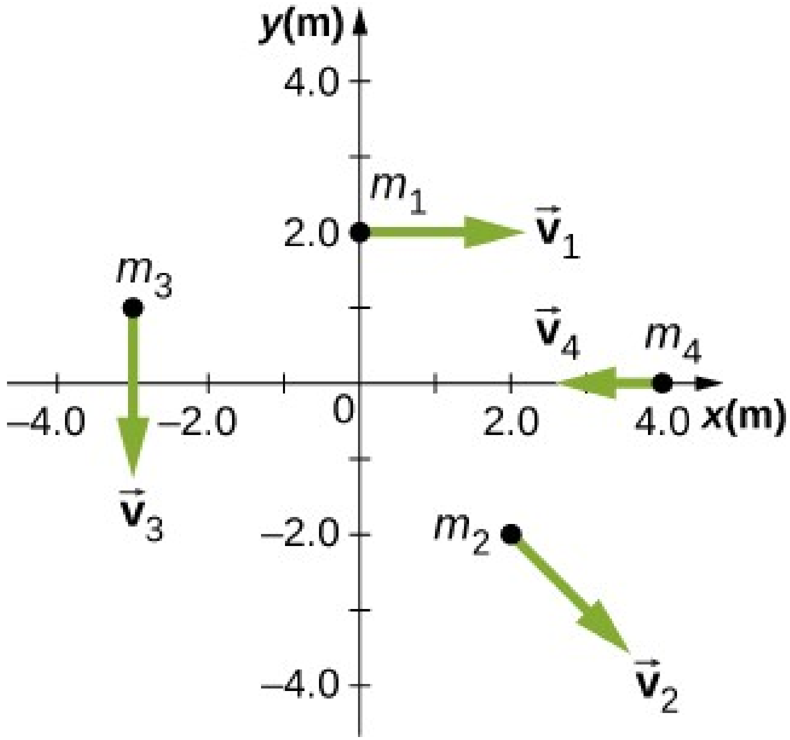


EXERCISE 32



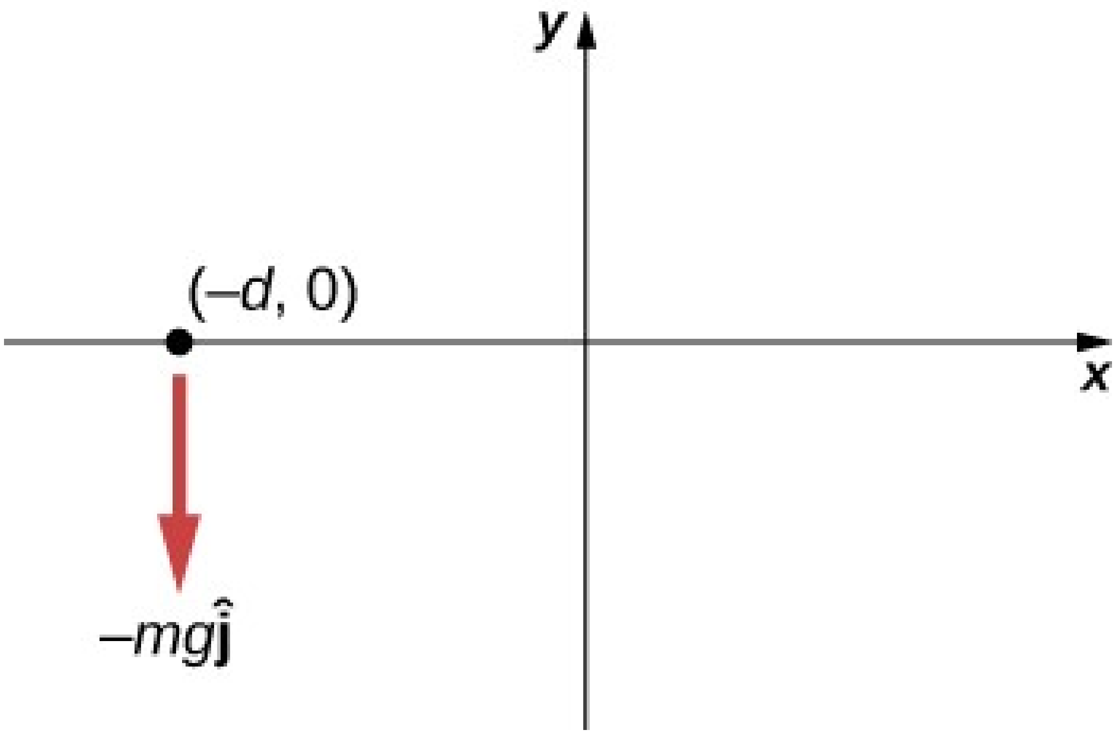
A solid cylindrical wheel of mass *M* and radius *R* is pulled by a force **F** applied to the center of the wheel at 37 degrees to the horizontal (see the following figure). If the wheel is to roll without slipping, what is the maximum value of F The coefficients of static and kinetic friction are

EXERCISE 38



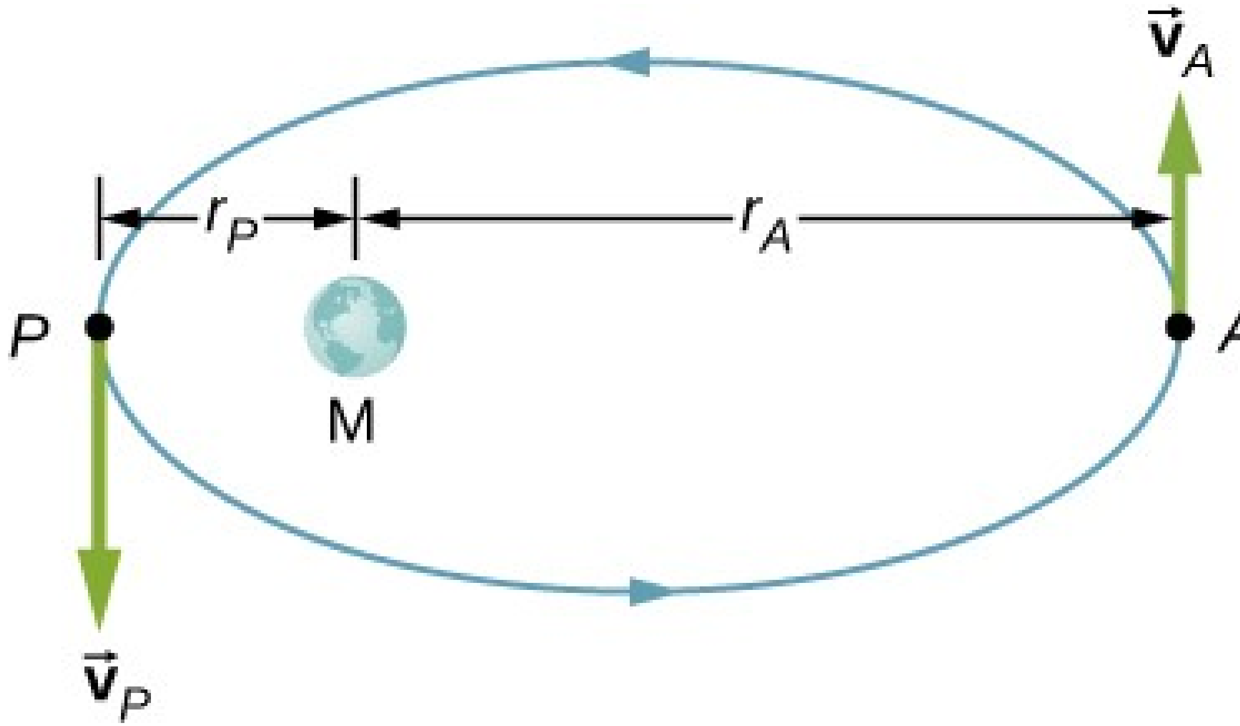
Use the right-hand rule to determine the directions of the angular momenta about the origin of the particles as shown below. The *z*-axis is out of the page.

EXERCISE 43



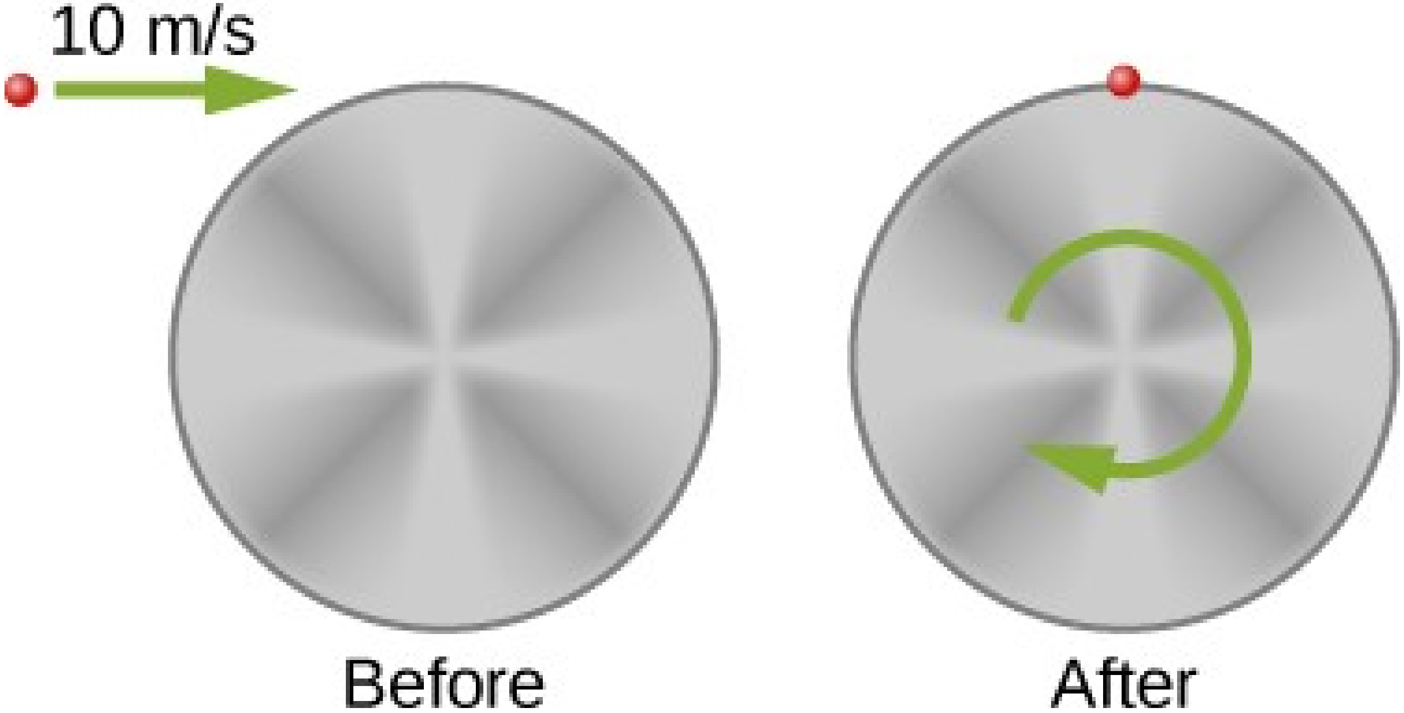
A particle of mass m is dropped at the point $(-d, 0)$ and falls vertically in Earth's gravitational field (a) What is the expression for the angular momentum of the particle around the z-axis, which points directly out of the page as shown below? (b) Calculate the torque on the particle around the z-axis. (c) Is the torque equal to the time rate of change of the angular momentum?

EXERCISE 56



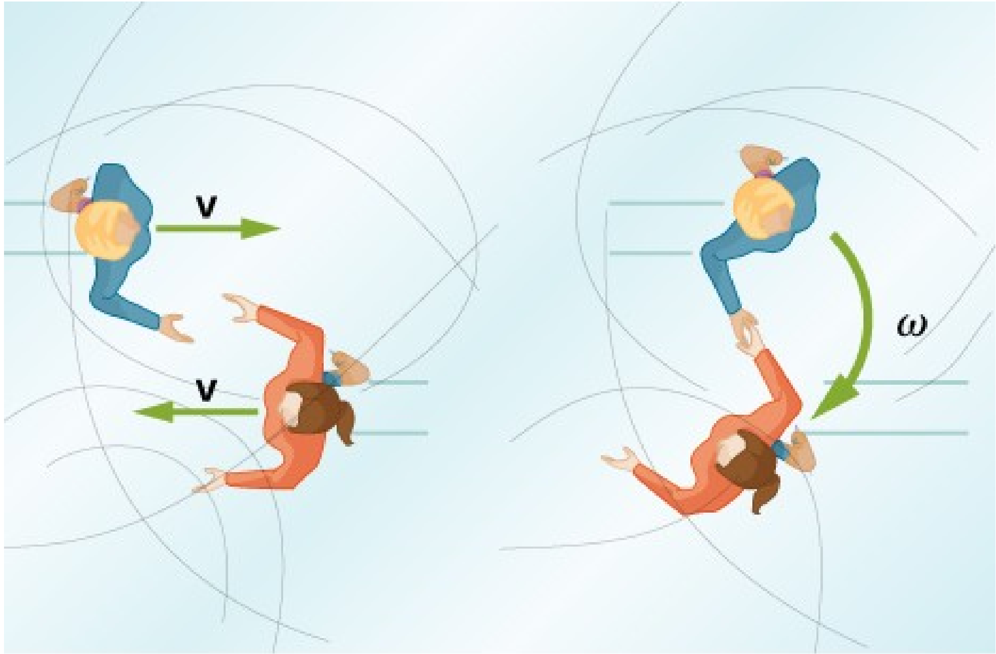
An Earth satellite has its apogee at 2500 km above the surface of Earth and perigee at 500 km above the surface of Earth. At apogee its speed is 6260 m/s. What is its speed at perigee? Earth's radius is 6370 km (see below). Use angular momentum conservation! L=mvr

EXERCISE 58



Shown below is a small particle of mass 20 g that is moving at a speed of 10.0 m/s when it collides and sticks to the edge of a uniform solid cylinder. The cylinder is free to rotate about its axis through its center and is perpendicular to the page. The cylinder has a mass of 0.5 kg and a radius of 10 cm, and is initially at rest. (a) What is the angular velocity of the system after the collision? (b) How much kinetic energy is lost in the collision?

EXERCISE 65



(a) (b)

Twin skaters approach one another as shown below and lock hands. (a) Calculate their final angular velocity, given each had an initial speed of 2.50 m/s relative to the ice. Each has a mass of 70.0 kg, and each has a center of mass located 0.800 m from their locked hands. You may approximate their moments of inertia to be that of point masses at this radius. (b) Compare the initial kinetic energy and final kinetic energy.
[Use angular momentum conservation! Note you can also use energy conservation.]