Chapter 5: Applying Newton's laws
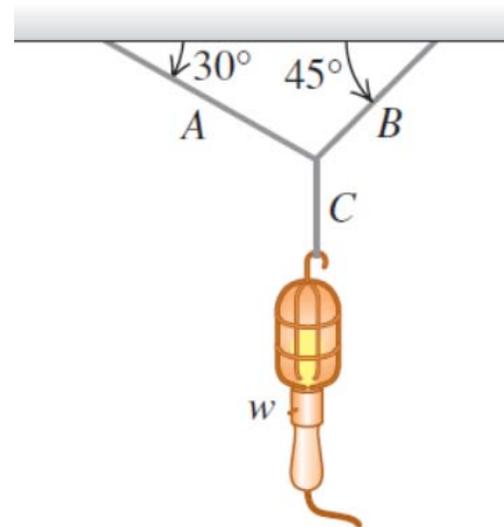
Using Newton's 1st law

The sum of all forces is zero when an object has constant velocity,

$$\sum_{i=1}^{N} \vec{F_i} = 0$$

EXAMPLE

(i)   Find the tension in C.

(ii) Find the tension in B.

(iii) Find the tension in A.

Using Newton's 2nd law

Newton's second law is useful in the general case of an accelerating body,

$$\sum_{i=1}^{N} \vec{F_i} = m\vec{a}$$

EXAMPLE

Two boxes are connected to each end of a lightweight vertical rope. A constant upward force of 90.0 N is applied to box A. Starting from rest, box B descends with an acceleration of 1.2 m/s². The tension in the rope connecting the two boxes is 36.0 N.

(i) Determine the mass of box B.

(ii) Determine the mass of box A.

An object is hanging by a string from the ceiling of an elevator. The elevator is moving upward with a constant speed. What is the magnitude of the tension in the string?
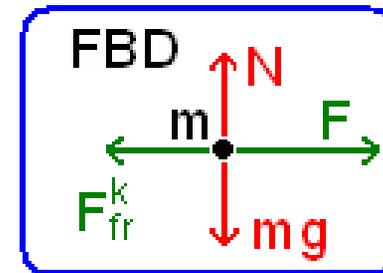
A. The tension in the string is zero.

B. The magnitude of the tension in the string is equal to the magnitude of the weight of the object.

C. The magnitude of the tension in the string is less than the magnitude of the weight of the object.
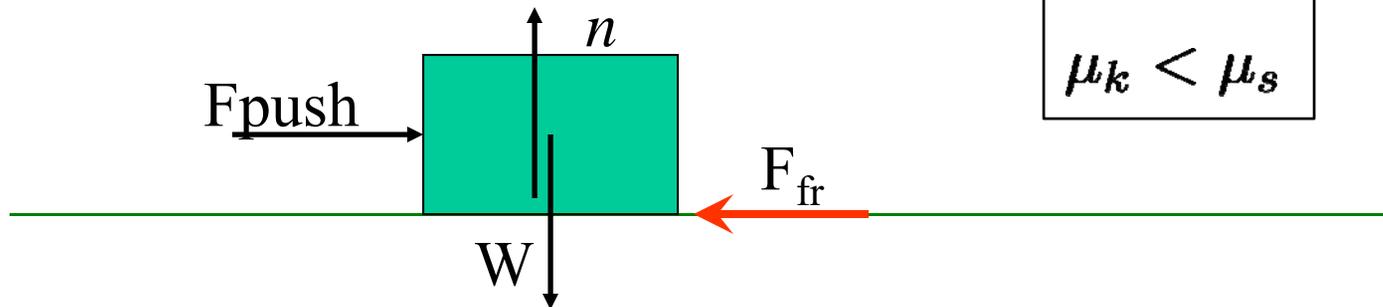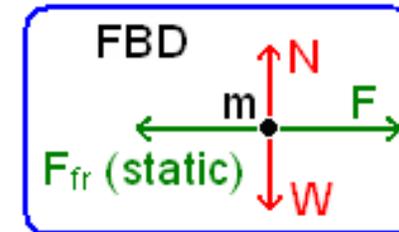
D. The tension in the string cannot be determined without knowing the speed of the elevator..

Simple model for friction

Kinetic friction
$(\vec{v} \neq 0)$

$$F_k = \mu_k N$$

FBD

N

m

F

F_{fr}^{k}

mg

Static friction
$(\vec{v} = 0)$

$$F_s \leq \mu_s N$$

FBD

N

m

F

F_{fr} (static)

W

Note:

$$\mu_k < \mu_s$$

n

Fpush

F_{fr}

W

A box slides down a frictionless plane inclined at an angle θ, above the horizontal. The gravitational force on the box is directed

A. at an angle θ, below the inclined plane.

B. parallel to the plane in the opposite direction as the movement of the box.

C. vertically.

D. parallel to the plane in the same direction as the movement of the box.

A brick is resting on a rough incline as shown in the figure. The friction force acting on the brick, along the incline, is

A. zero.

B. equal to the weight of the brick.

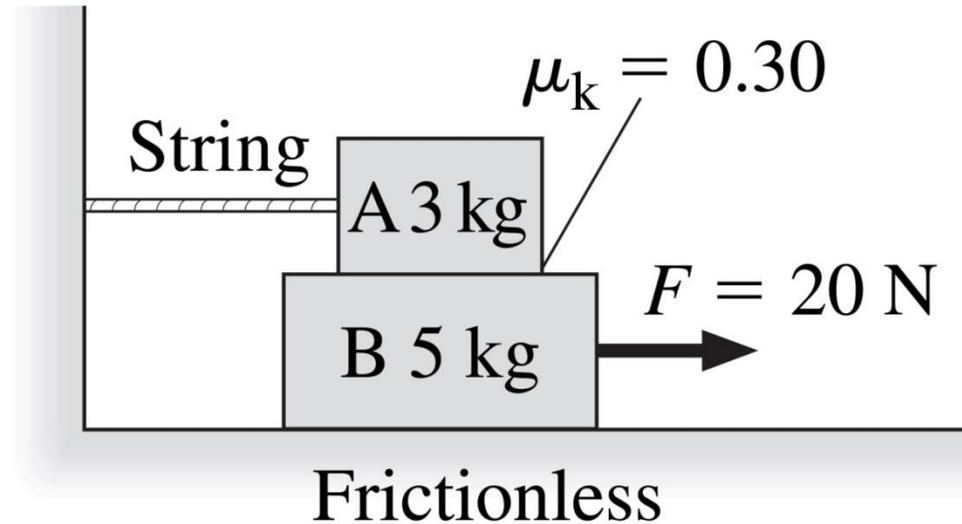C. less than the weight of the brick.

D. greater than the weight of the brick.
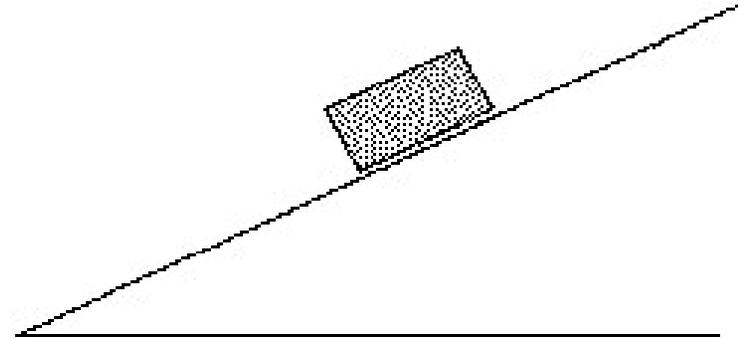
A crate lies on a plane tilted at an angle $\theta = 24.0°$ to the horizontal, with $\mu_k = 0.30$. Determine the acceleration of the block as it slides down the plane.
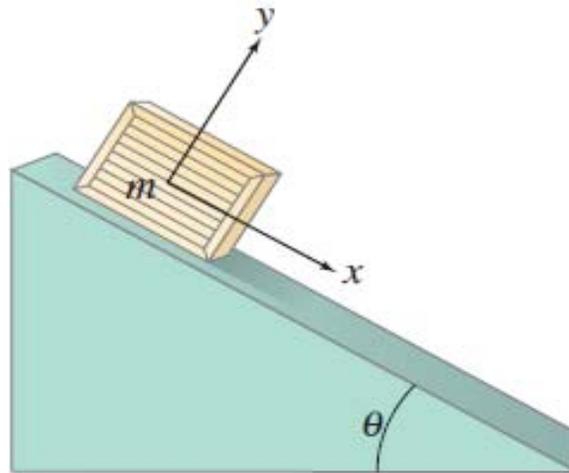
Determine the acceleration of the box.

Which pair of forces is an action/reaction pair?

$\mu_k = 0.30$

String

A 3 kg

B 5 kg

$F = 20 \text{ N}$

Frictionless

A. The string tension and the friction force acting on A.

B. The normal force on A due to B and the weight of A.

C. The normal force on A due to B and the weight of B.

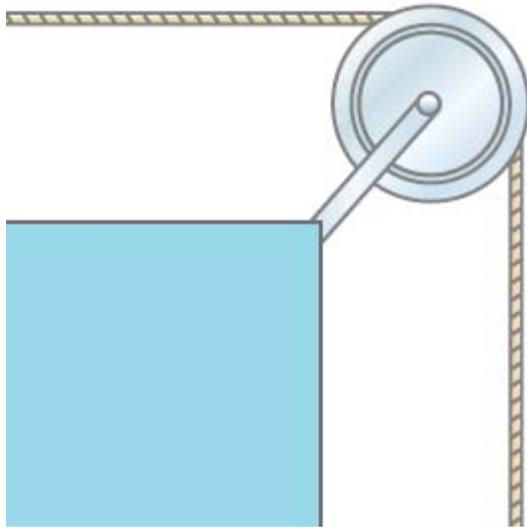D. The friction force acting on A and the friction force acting on B.

Example Problem

What is the acceleration of block B?

$\mu_k = 0.30$

String

A 3 kg

$F = 20$ N

B 5 kg
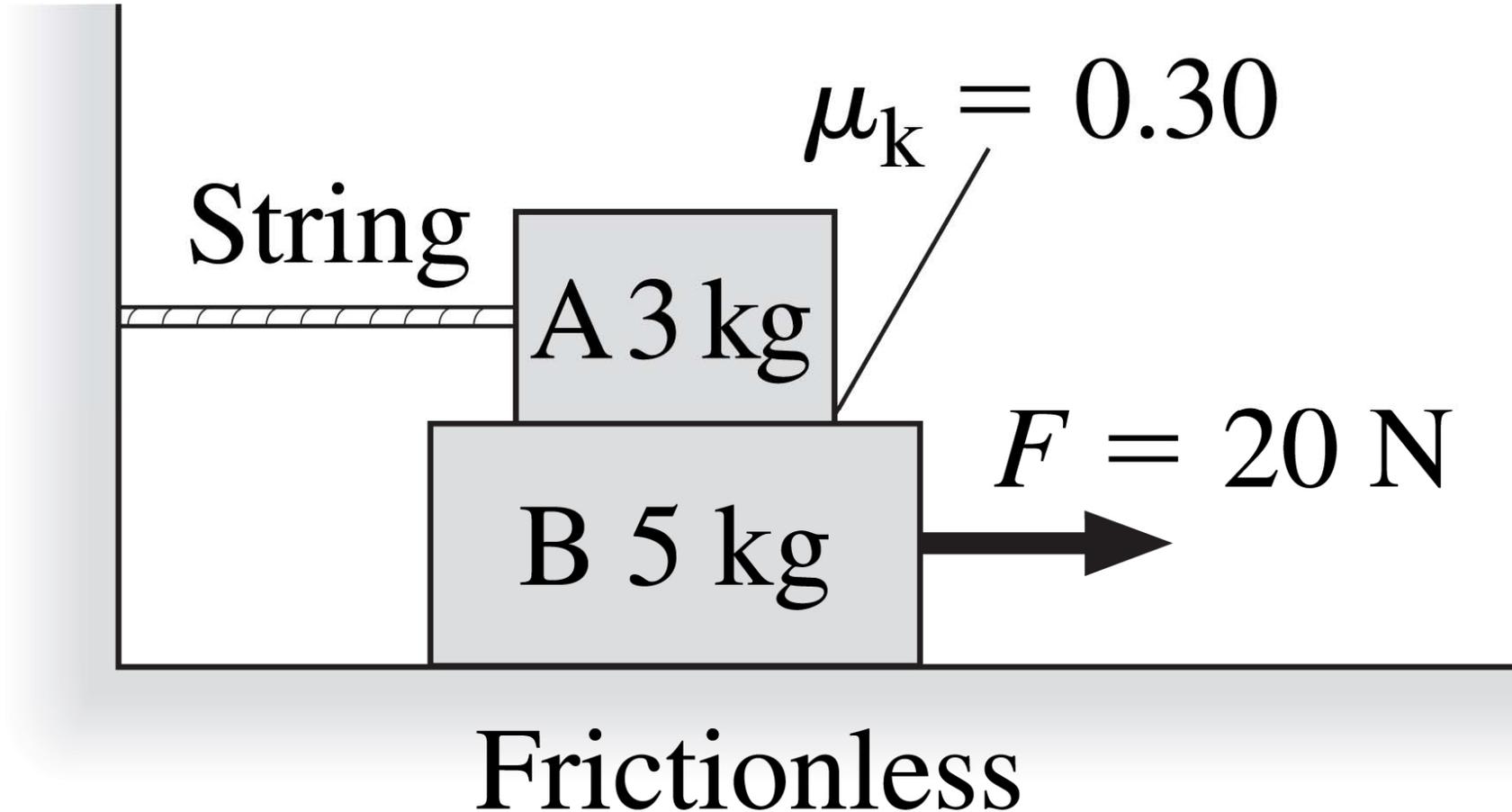
Frictionless

Pulleys

For now, let us assume an ideal pulley, *i.e.*, massless and frictionless.

An ideal pulley applies a perpendicular force at each contact, which changes the direction of the tension.
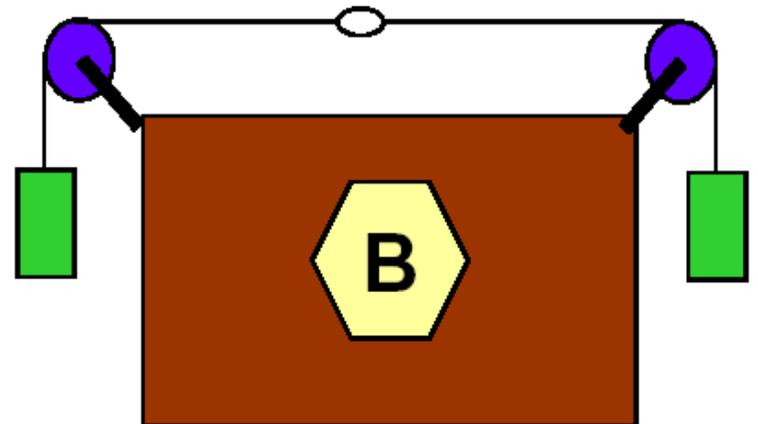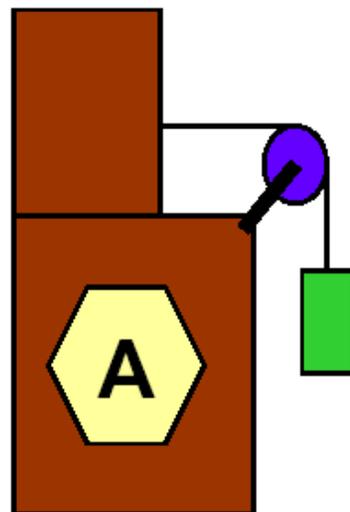
In the figures shown, all the green boxes have the same mass and all the pulleys are identical. In which case is the tension in the string greater?

1. Case A

2. Case B

3. They are the same

4. You can't tell.

Two objects having masses m_1 and m_2 are connected to each other as shown in the figure and are released from rest. There is no friction on the table surface or in the pulley. The masses of the pulley and the string connecting the objects are completely negligible. What must be true about the tension T in the string just after the objects are released?

A. $T < m_2 g$

B. $T = m_2 g$

C. $T > m_2 g$

D. It depends on the mass of m_1
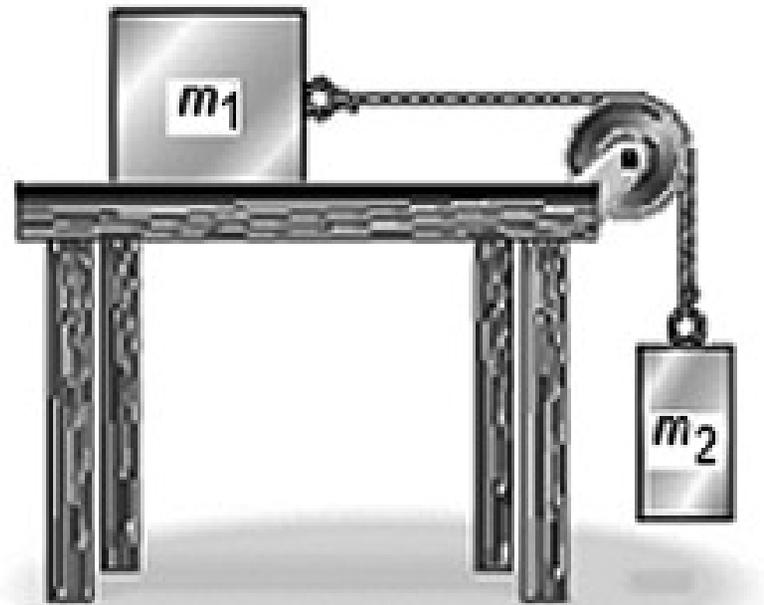
(II) Figure 4–53 shows a block (mass m_A) on a smooth hori-
zontal surface, connected by a thin cord that passes over
a pulley to a second block (m_B), which hangs vertically.
(a) Draw a free-body diagram for each block, showing the
force of gravity on each, the force (tension) exerted by the
cord, and any normal force. (b) Apply Newton's second law
to find formulas for the acceleration of the system and for
the tension in the cord. Ignore friction and the masses of
the pulley and cord.
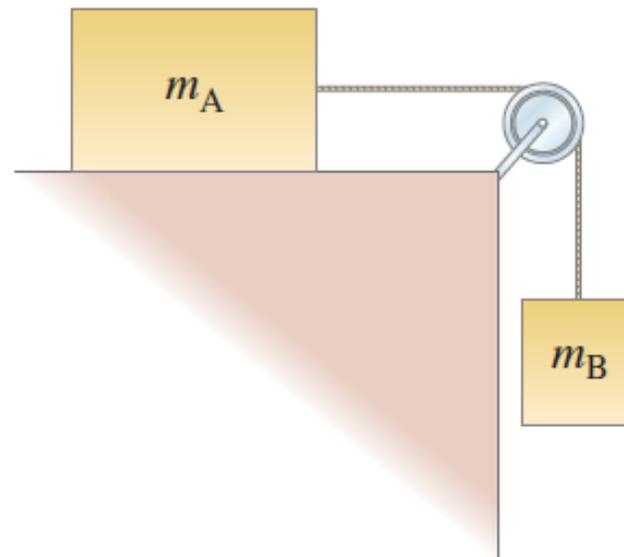
(III) Two masses m_A = 2.0 kg and m_B = 5.0 kg are on inclines and are connected together by a string as shown in Fig. 4–61. The coefficient of kinetic friction between each mass and its incline is μ_k = 0.30. If m_A moves up, and m_B moves down, determine their acceleration. [Ignore masses of the (frictionless) pulley and the cord.]
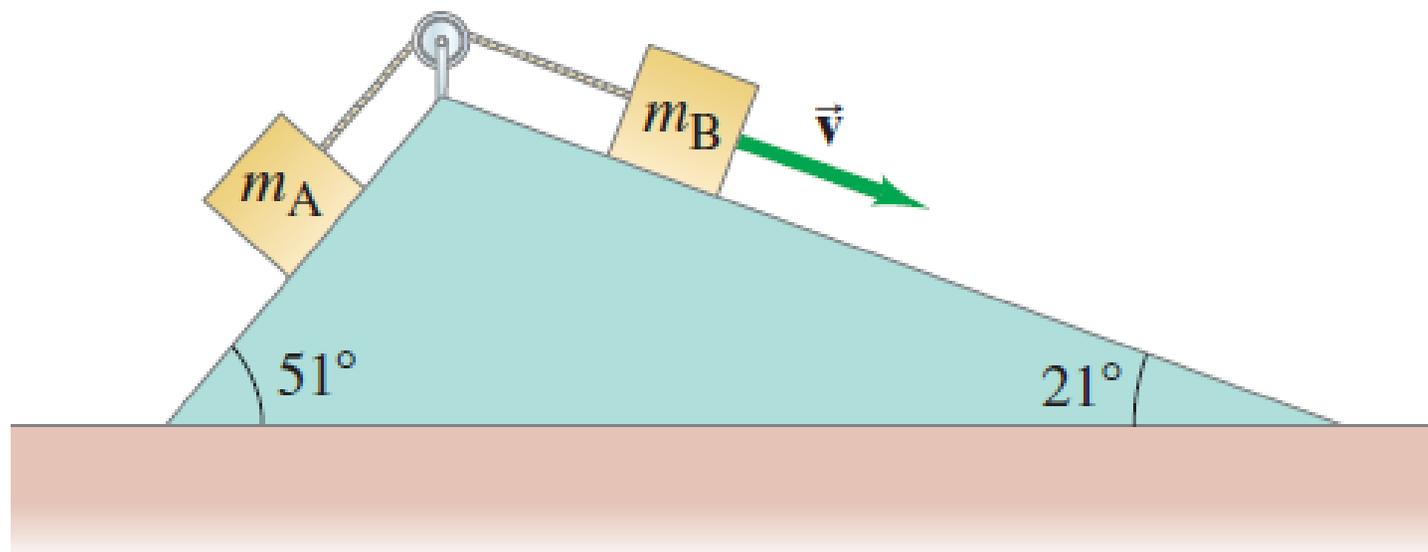
Dynamics of circular motion

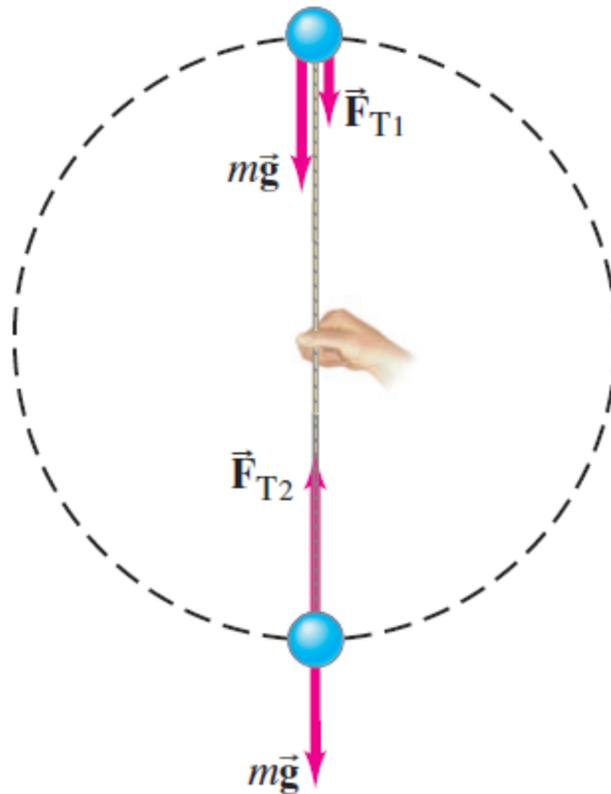For uniform circular motion the NET FORCE is directed toward the center of the circle at all times.
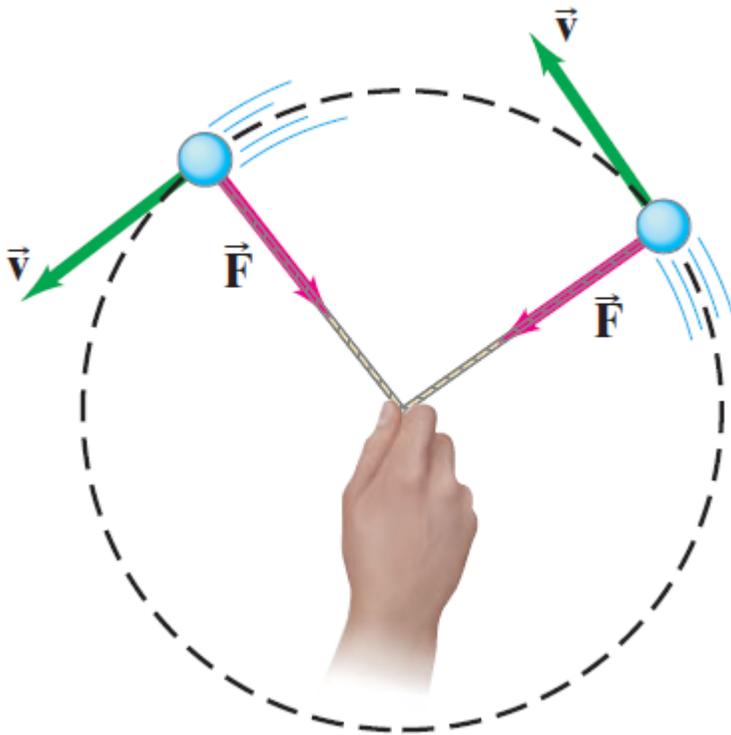
The net force in the radial direction is given by

$$\sum F_\mathrm{rad} = ma_\mathrm{rad}$$

$$= m\frac{v^2}{r}$$

A 0.150 kg ball on the end of a 1.10 m long, lightweight cord is swung in a *vertical* circle. Determine the minimum speed the ball must have at the top of its arc so that the ball continues moving in a circle.

A toy car with mass 0.800 kg travels at **constant** speed on the inside of a track that is a vertical circle with radius 5.00 m. The normal force exerted by the track on the car when it is at the top of the track is 15.2 N. What is the normal force on the car when it is at the bottom of the track (point A)?

B

$v = 12.0 \text{ m/s}$

5.00 m

$v = 12.0 \text{ m/s}$

A
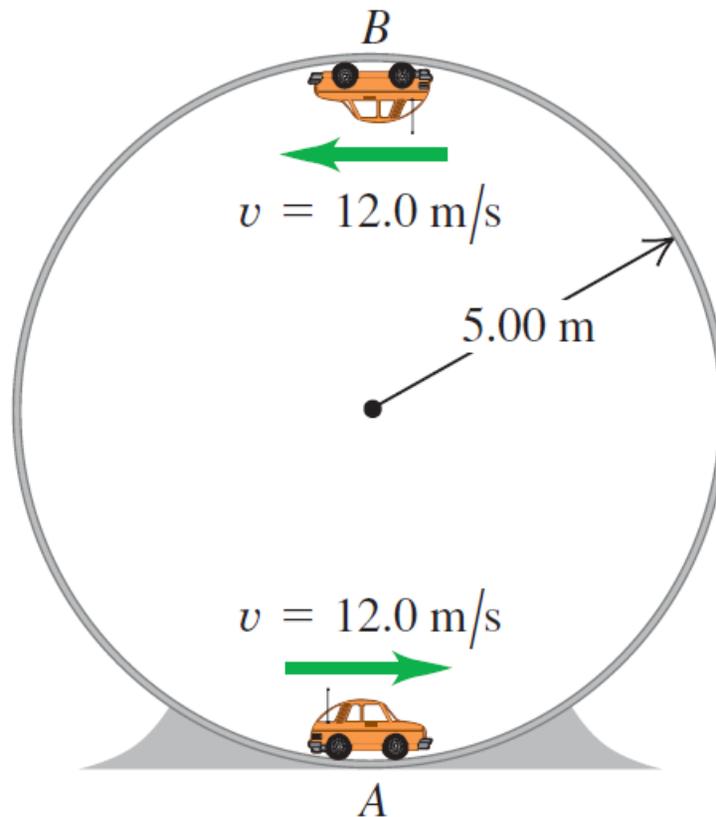
An object moves in a circular path at a constant speed. What is the direction of the net force acting on the object?

A. The net force points in the same direction as the motion of the object.

B. The net force points in the direction opposite to the motion of the object.

C. The net force is directed away from the center of the circular path.

D. The net force is directed toward the center of the circular path.

A curve in a road is banked, which means that the roadway is tilted toward the inside of the curve as seen in the opening photograph for this chapter. Suppose the designated speed for the ramp is to be 13.4 m/s (30.0 mi/h) and the radius of the curve is 35.0 m. At what angle should the curve be banked for the car to not have to rely on friction to round the curve without skidding?
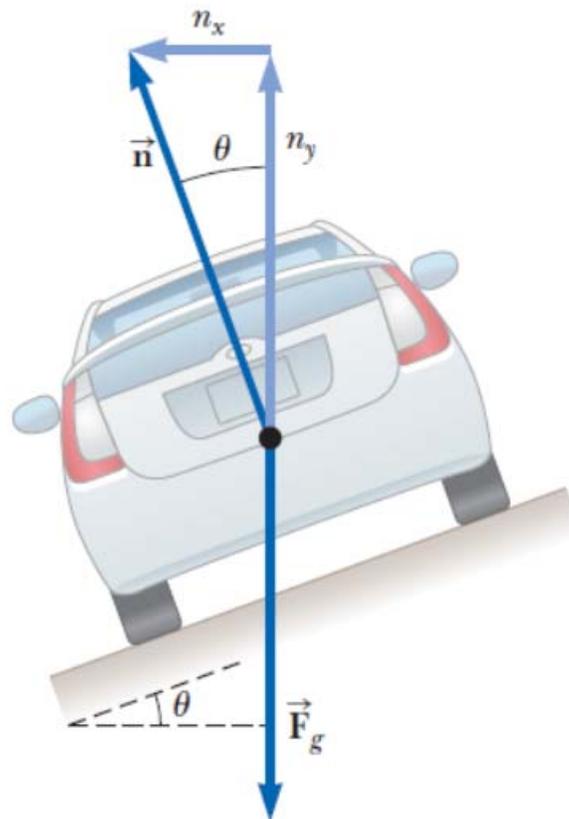
Drag as a velocity dependent force

The drag force (fluid resistance), f, of small objects moving at low speed is approximately proportional to the velocity, but approximately proportional to the velocity squared for larger objects moving at faster speeds.

For simplicity, lets consider the linear relationship, $f = kv$, where k depends on the particle's size and shape, and the properties of the fluid.

The drag force larger objects moving at faster speed is approximately

$$f = Dv^2$$

where D also depends on the particle's size and shape, and the properties of the fluid.

Drag as a velocity dependent force

The drag force (fluid resistance), f, of small objects moving at low speed is approximately proportional to the velocity, but approximately proportional to the velocity squared for larger objects moving at faster speeds.

Let us consider the linear relationship, $f = Dv^2$, where D depends on the particle's size and shape, and the properties of the fluid.
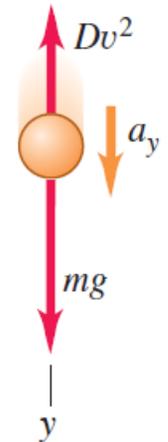
The net force from the free body diagram gives

$$\sum_i F_{yi} = mg - Dv_y^2 = ma_y$$

Substituting $a_y = \dfrac{dv_y}{dt}$ allows us to write $m\dfrac{dv_y}{dt} = mg - Dv_y^2$

For an object dropped from rest at $t = 0$, we get $\displaystyle\int_0^{v_y} \frac{dv_y'}{\frac{mg}{D} - v_y'^2} = \int_0^t \frac{D}{m}dt'$

terminal velocity

$$\Rightarrow \sqrt{\frac{D}{mg}} \tanh^{-1}\left(v_y\sqrt{\frac{D}{mg}}\right) = \frac{D}{m}t \qquad \Rightarrow \qquad v_y = \sqrt{\frac{mg}{D}} \tanh\left(\sqrt{\frac{gD}{m}}t\right)$$

Fundamental forces of nature

The **gravitational interaction** is a weak interaction between two physical objects that have mass and energy.

The **electromagnetic interaction** is mediated by photons and is responsible for atomic structure, chemical reactions, the attractive and repulsive electromagnetic forces associated with electrically charged or magnetically polarized particles.

The **strong interaction** is responsible for the strong nuclear force, and the interaction is mediated by gluons that confine quarks in hadrons.

The **weak interaction** is mediated by the heavy W and Z bosons. It can violate parity symmetry, it can change the flavor of quarks, and it is responsible for radioactive decay.