Chapter 5: Applying Newton's laws

Using Newton's 1st law

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

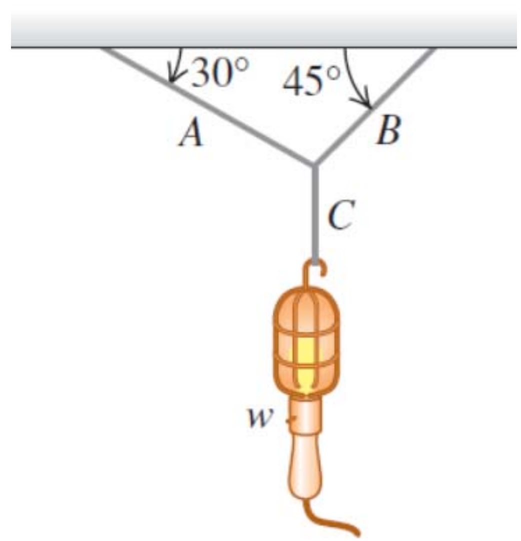
$$\sum_{i=1}^{N} \vec{F}_i = 0$$

EXAMPLE

(i) Find the tension in C.

(ii) Find the tension in B.

(iii) Find the tension in A.



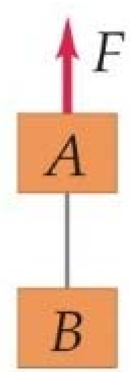
Using Newton's 2nd law

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/s^2. The tension in the rope connecting the two boxes is 36.0 N.



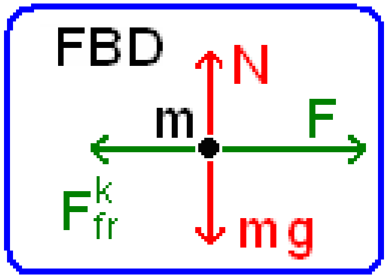
(i) Determine the mass of box B.

(ii) Determine the mass of box A.

Simple model for friction

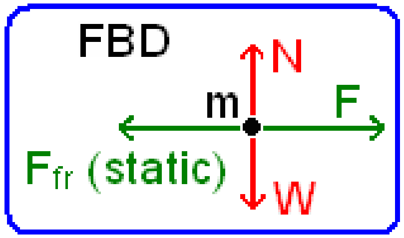
Kinetic friction ($\vec{v} \neq 0$)

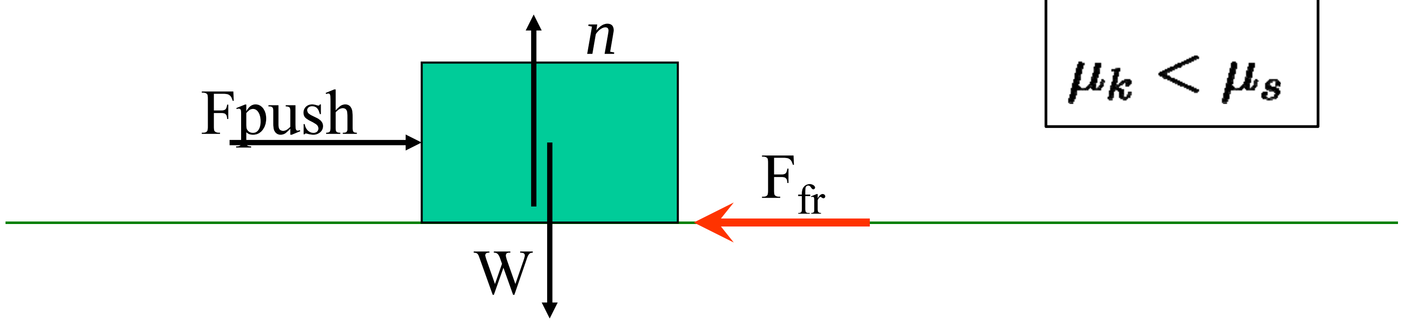
$$F_k = \mu_k N$$



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

$$F_s \leq \mu_s N$$

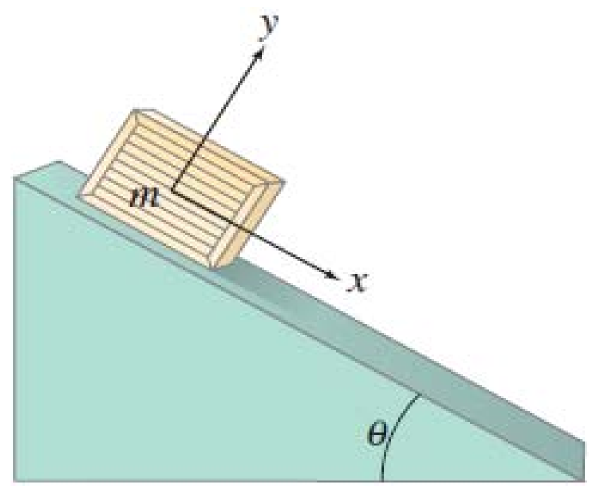




Note:

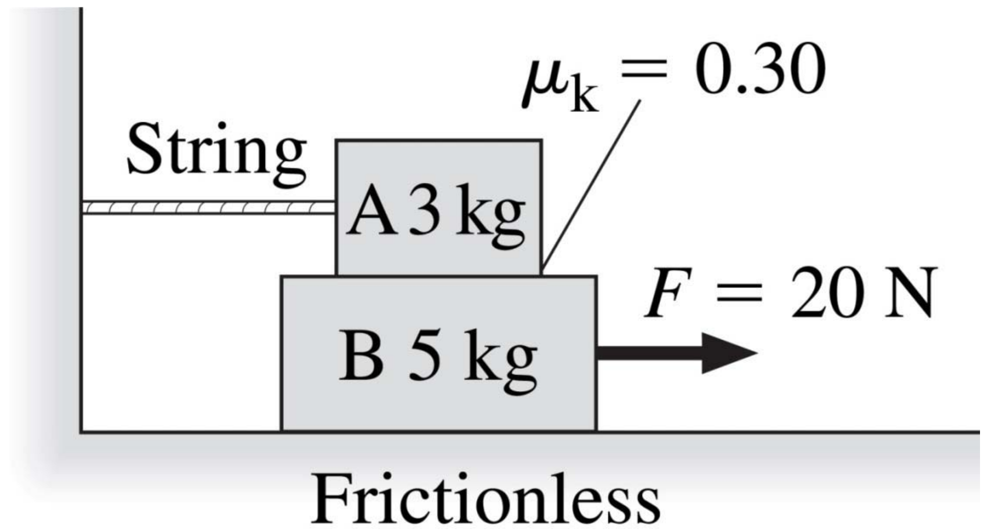
$$\mu_k < \mu_s$$

A crate lies on a plane tilted at an angle $\theta = 24.0^o$ 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?



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

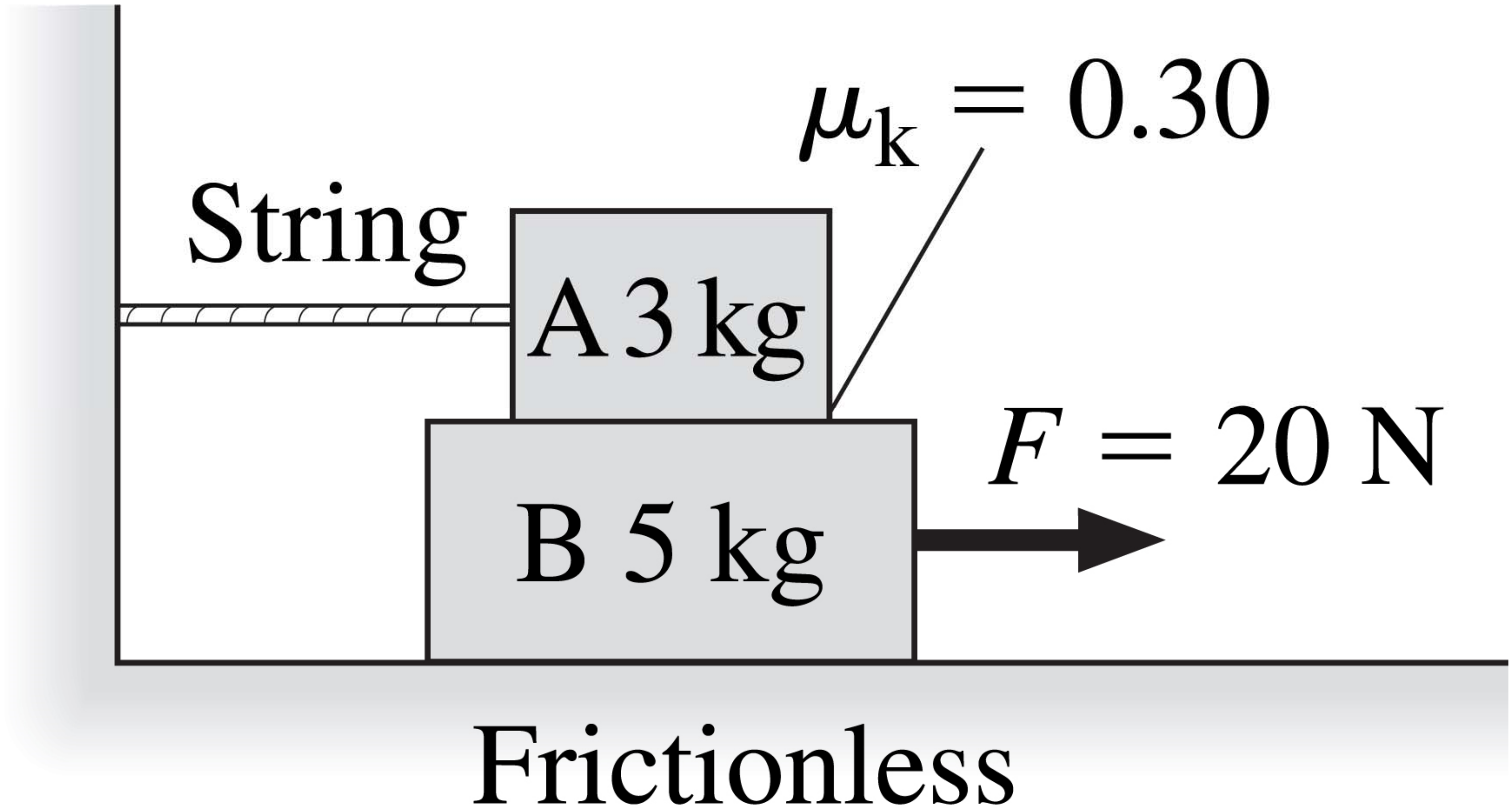
B. The normal force on A due to B and the weight of A.

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.

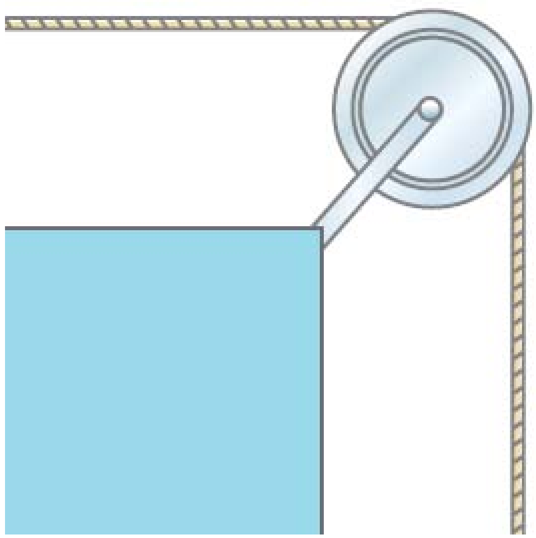
Example Problem

What is the acceleration of block B?



Pulleys

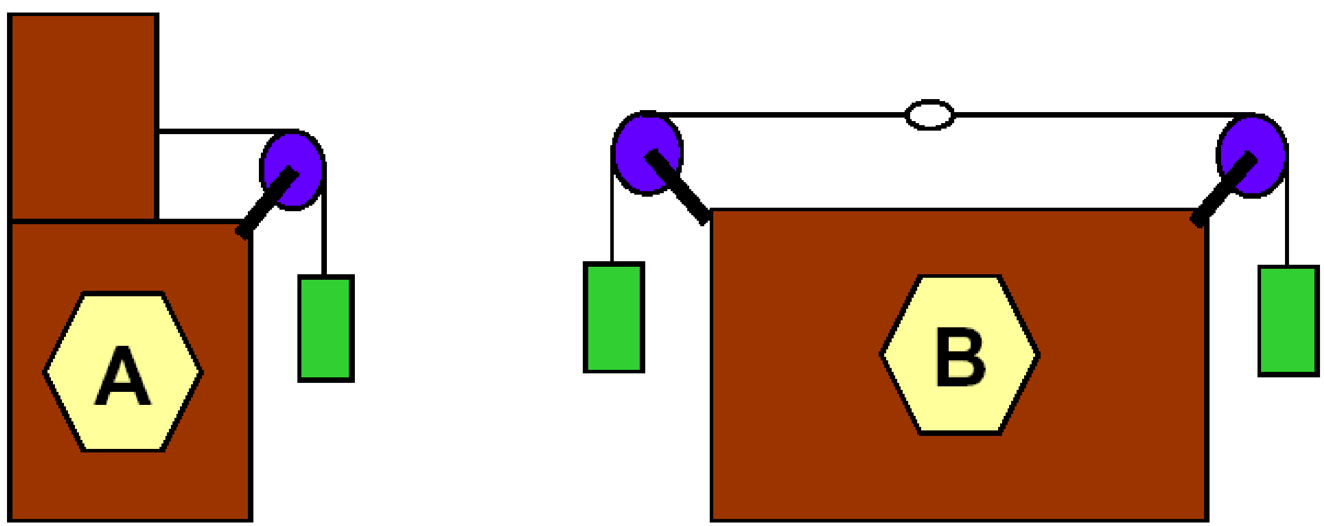
For now, let us assume an ideal pulley, *i.e.*, massless and frictionless.



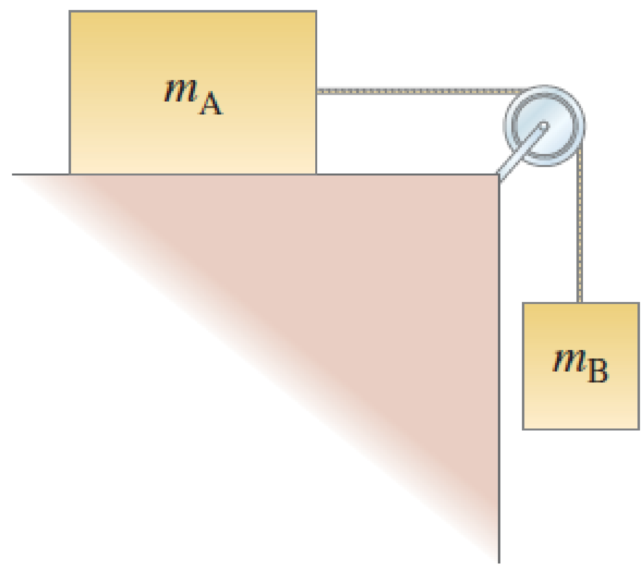
An ideal pulley applies a perpendicular force at each contact, which changes the direction of the tension.

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?

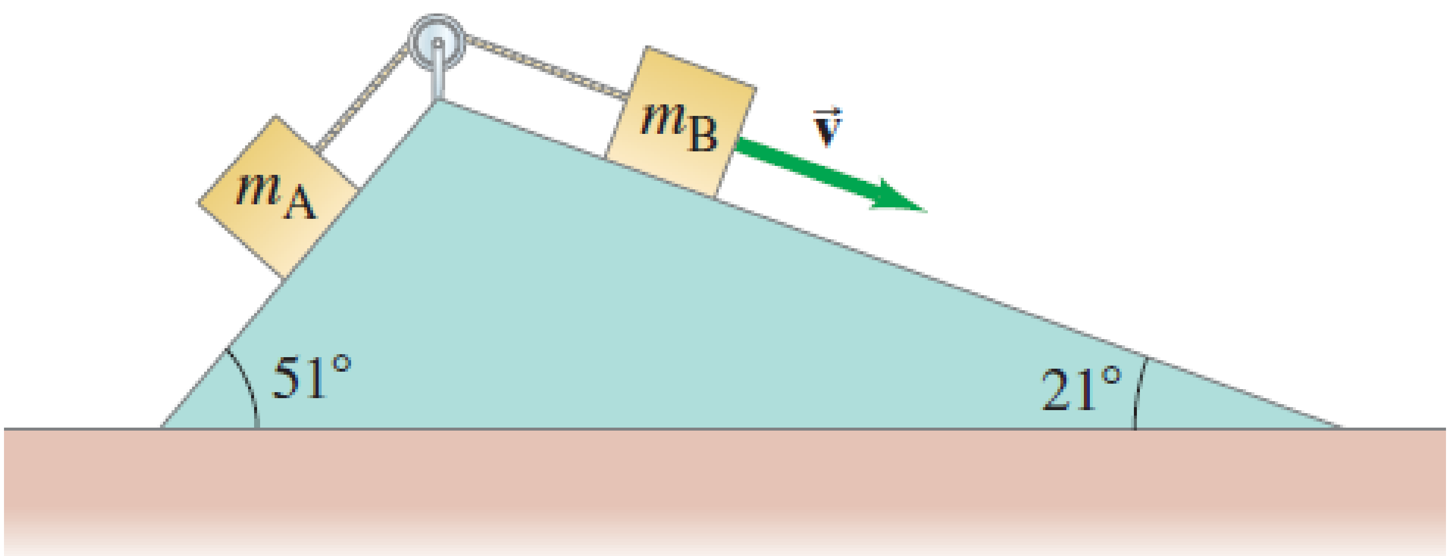
1. Case A
2. Case B
3. They are the same
4. You can't tell.



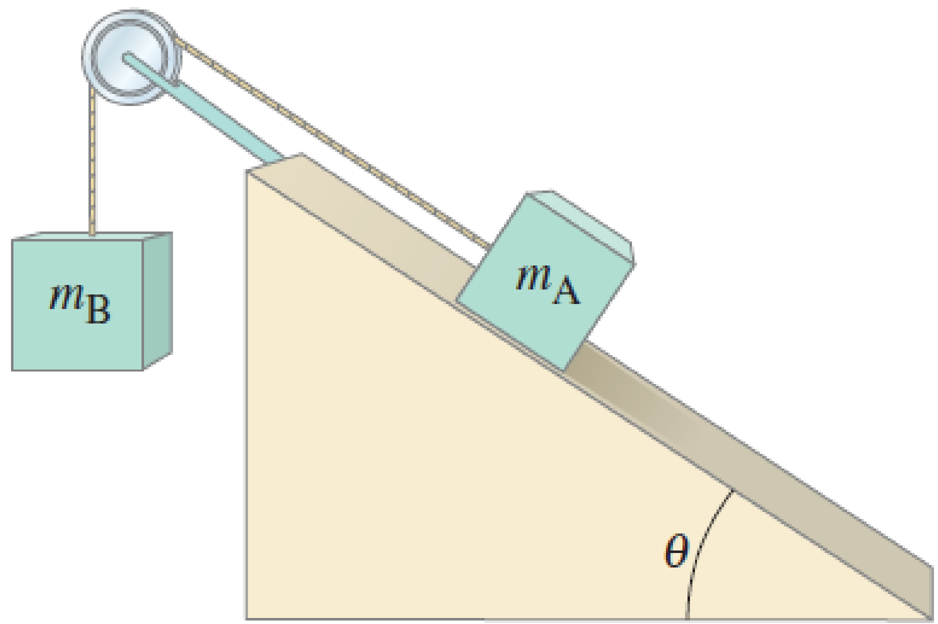
(II) Figure 4–53 shows a block (mass m_A) on a smooth horizontal surface, connected by a thin cord that passes over a pulley to a second block (m_B), which hangs vertically. (*a*) Draw a free-body diagram for each block, showing the force of gravity on each, the force (tension) exerted by the cord, and 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 $m_A = 2.0\,\text{kg}$ and $m_B = 5.0\,\text{kg}$ 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 $\mu_k = 0.30$. If m_A moves up, and m_B moves down, determine their acceleration. [Ignore masses of the (frictionless) pulley and the cord.]

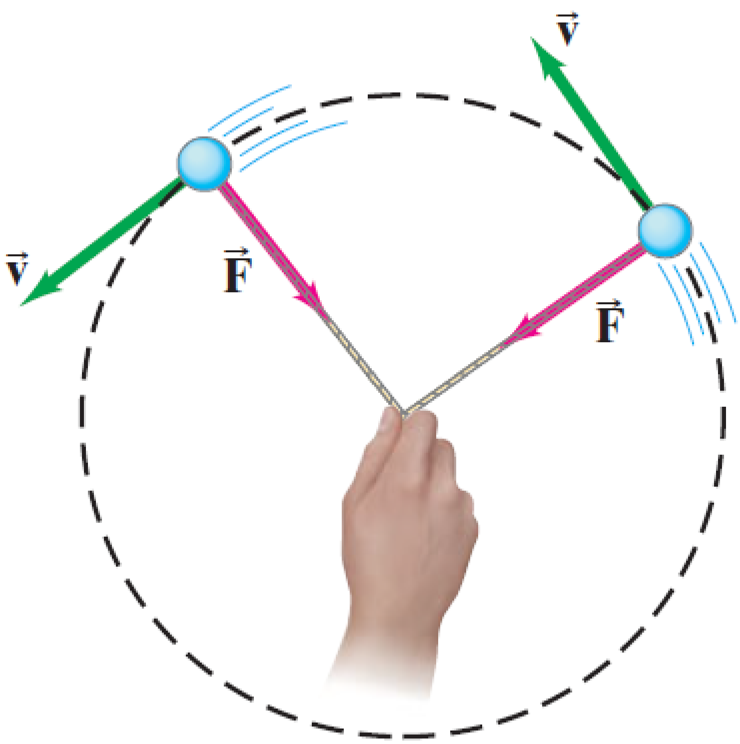


(III) (*a*) Suppose the coefficient of kinetic friction between m_A and the plane in Fig. 4–62 is $\mu_k = 0.15$, and that $m_A = m_B = 2.7$ kg. As m_B moves down, determine the magnitude of the acceleration of m_A and m_B, given $\theta = 34°$. (*b*) What smallest value of μ_k will keep the system from accelerating? [Ignore masses of the (frictionless) pulley and the cord.]



Dynamics of circular motion

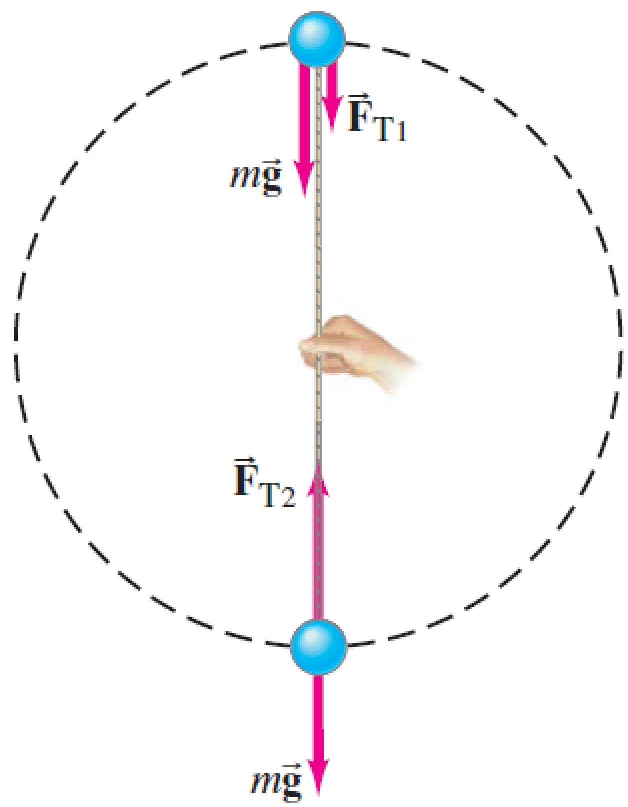
For uniform circular motion the NET FORCE is directed toward the center of the circle at all times.



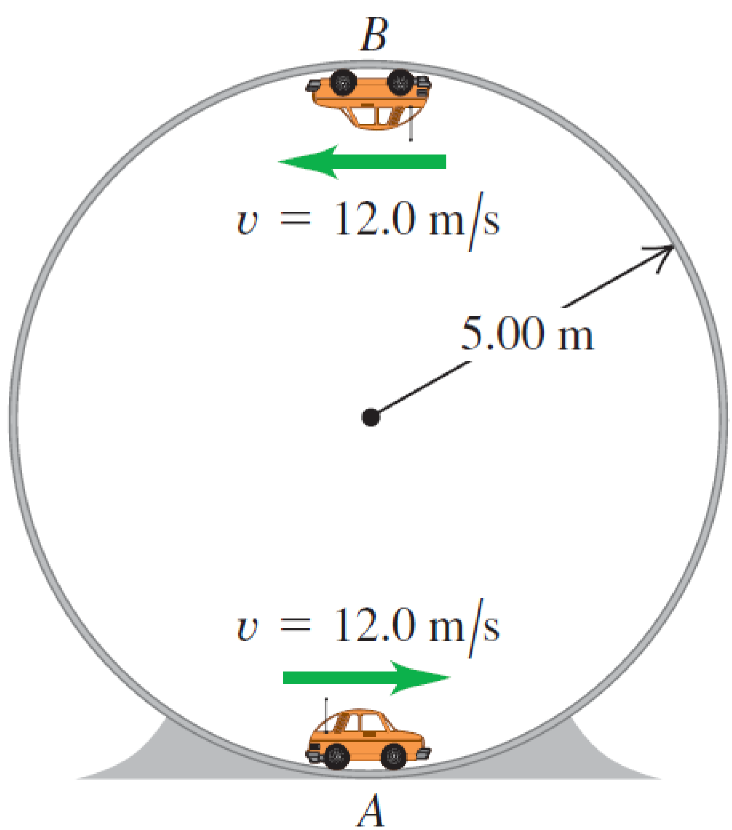
The net force in the radial direction is given by

$$\sum F_{\mathrm{rad}} = m a_{\mathrm{rad}} = m \frac{v^2}{r}$$

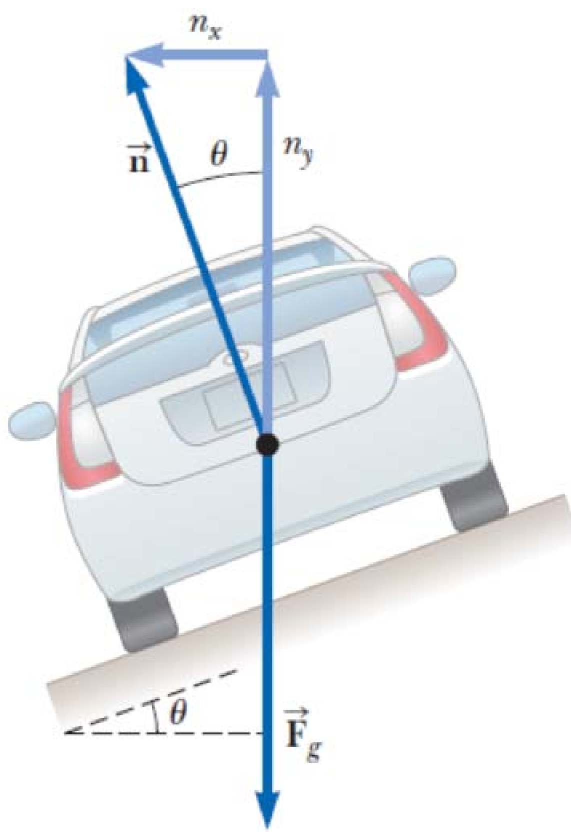
A 0.150 kg ball on the end of a 1.10 m long, lightweight cord is swung in a *vertical* circle. Determine the minimum speed the ball must have at the top of its arc so that the ball continues moving in a circle.



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)?



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.

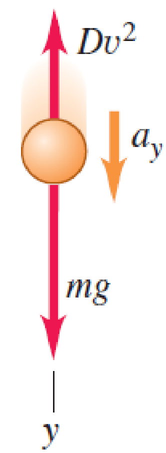
The drag force larger objects moving at faster speed is approximately

$$f = Dv^2$$

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

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

terminal velocity

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

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.