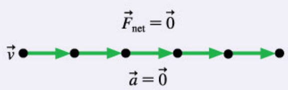
*Physics 4A*
*Chapter 5: Force and Motion and*
*Chapter 6: Dynamics I: Motion Along a Line*

## GENERAL PRINCIPLES

### Newton's First Law

An object at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force on the object is zero.




The first law tells us that no "cause" is needed for motion. Uniform motion is the "natural state" of an object.

Newton's laws are valid only in inertial reference frames.

### Newton's Zeroth Law

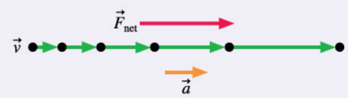
An object responds only to forces acting on it *at this instant*.

### Newton's Second Law

An object with mass $m$ has acceleration

$$\vec{a} = \frac{1}{m}\vec{F}_{net}$$

where $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all the individual forces acting on the object.




The second law tells us that a net force causes an object to accelerate. This is the connection between force and motion.



## IMPORTANT CONCEPTS

**Acceleration** is the link to kinematics.

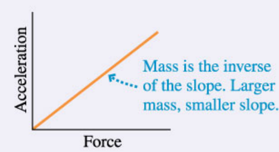
From $\vec{F}_{net}$, find $\vec{a}$.
From $a$, find $v$ and $x$.

$\vec{a} = \vec{0}$ is the condition for **equilibrium**.

An object **at rest** is in equilibrium.
So is an object with **constant velocity**.

Equilibrium occurs if and only if $\vec{F}_{net} = \vec{0}$.

**Mass** is the resistance of an object to acceleration. It is an intrinsic property of an object.




**Force** is a push or a pull on an object.

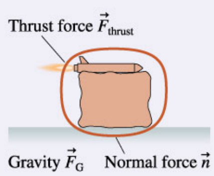
- Force is a vector, with a magnitude and a direction.
- Force requires an agent.
- Force is either a contact force or a long-range force.



## KEY SKILLS

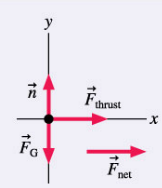
### Identifying Forces

Forces are identified by locating the points where other objects touch the object of interest. These are points where contact forces are exerted. In addition, objects with mass feel a long-range gravitational force.




### Free-Body Diagrams

A free-body diagram represents the object as a particle at the origin of a coordinate system. Force vectors are drawn with their tails on the particle. The net force vector is drawn beside the diagram.

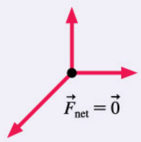


# GENERAL PRINCIPLES

## Two Explanatory Models

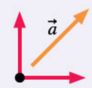
An object on which there is no net force is in **mechanical equilibrium**.

- Objects at rest.
- Objects moving with constant velocity.
- Newton's second law applies with $\vec{a} = \vec{0}$.




An object on which the net force is constant undergoes **dynamics with constant force**.

- The object accelerates.
- The kinematic model is that of constant acceleration.
- Newton's second law applies.




## A Problem-Solving Strategy

A four-part strategy applies to both equilibrium and dynamics problems.

**MODEL** Make simplifying assumptions.

**VISUALIZE**

Go back and forth between these steps as needed.

- Translate words into symbols.
- Draw a sketch to define the situation.
- Draw a motion diagram.
- Identify forces.
- Draw a free-body diagram.

**SOLVE** Use Newton's second law:

$$\vec{F}_{net} = \sum_i \vec{F}_i = m\vec{a}$$

"Read" the vectors from the free-body diagram. Use kinematics to find velocities and positions.

**ASSESS** Is the result reasonable? Does it have correct units and significant figures?



# IMPORTANT CONCEPTS

Specific information about three important descriptive models:

**Gravity** $\vec{F}_G = (mg, \text{downward})$

**Friction** $\vec{f}_s = (0 \text{ to } \mu_s n, \text{direction as necessary to prevent motion})$

$\vec{f}_k = (\mu_k n, \text{direction opposite the motion})$

$\vec{f}_r = (\mu_r n, \text{direction opposite the motion})$

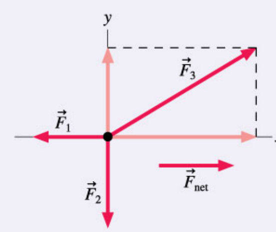
**Drag** $\vec{F}_{drag} = \left(\frac{1}{2} C\rho A v^2, \text{direction opposite the motion}\right)$

Newton's laws are vector expressions. You must write them out by **components**:

$$(F_{net})_x = \sum F_x = ma_x$$

$$(F_{net})_y = \sum F_y = ma_y$$

The acceleration is zero in equilibrium and also along an axis perpendicular to the motion.






# APPLICATIONS

**Mass** is an intrinsic property of an object that describes the object's inertia and, loosely speaking, its quantity of matter.

The **weight** of an object is the reading of a spring scale when the object is at rest relative to the scale. Weight is the result of weighing. An object's weight depends on its mass, its acceleration, and the strength of gravity. An object in free fall is weightless.

A falling object reaches **terminal speed**

$$v_{term} = \sqrt{\frac{2mg}{C\rho A}}$$


Terminal speed is reached when the drag force exactly balances the gravitational force: $\vec{a} = \vec{0}$.



# Conceptual Questions and Example Problems from Chapters 5 and 6

**Conceptual Question 5.7**

An object experiencing a constant force accelerates at 10 m/s$^2$. What will be the acceleration of this object be if (a) The force is doubled? Explain. (b) The mass is doubled? (c) The force is doubled *and* the mass is doubled?

**5.7.** A force $F$ causes an object of mass $m$ to accelerate at $a = \frac{F}{m} = 10\ \text{m/s}^2$. Let $a'$ be the new acceleration.

**(a)** If the force is doubled, $(2F) = ma' \Rightarrow a' = 2\left(\frac{F}{m}\right) = 2a = 20\ \text{m/s}^2$. The acceleration is proportional to the force, so if the force is doubled, the acceleration is also doubled.

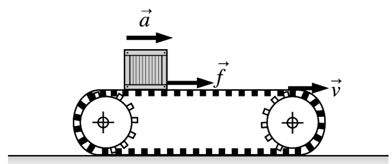
**(b)** Doubling the mass means that $F = (2m)a' \Rightarrow a' = \frac{1}{2}\left(\frac{F}{m}\right) = \frac{a}{2} = 5.0\ \text{m/s}^2$.

**(c)** If the force and mass are both doubled, then $(2F) = (2m)a' \Rightarrow a' = \frac{F}{m} = a = 10\ \text{m/s}^2$.

## Conceptual Question 5.13

Is it possible for the friction force on an object to be in the direction of motion? If so, give an example. If not, why not?

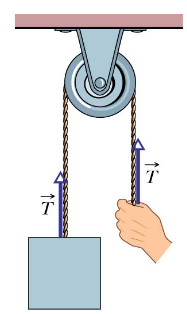
**5.13.**




Yes, it is possible for the friction force on an object to be in the same direction as the object's motion. Consider the case shown in the figure, in which a box is dropped onto a moving conveyer belt. The box is pushed horizontally in the same direction as its motion. While an observer standing next to the conveyer belt sees the box move to the right and eventually reach a constant speed (same as the conveyer belt), an observer standing on the conveyer belt would see the box slide to the left and eventually come to a stop. The direction of the kinetic friction force is opposite to the relative direction of motion between the two adjacent surfaces. In the example above, the box is moving to the left in the reference frame of the conveyer belt and, as expected, the kinetic friction force is to the right.

## Conceptual Question 5.A

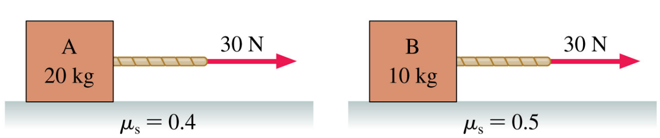
The body that is suspended by a rope in the figure below has a weight of 75 N. Is the tension T equal to, greater than, or less than 75 N when the body is moving downward at decreasing speed?




The tension is greater than 75 N. The acceleration points upward so the tension must be greater than the weight.

## Conceptual Question 6.13

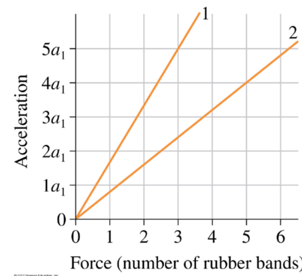
Boxes A and B in the figure below both remain at rest. Is the friction force on A larger than, smaller than, or equal to the frictional force on B? Explain.




**6.13.** Both boxes are in equilibrium and the net force on each is zero. The static friction force to the left must be exactly the same magnitude as the tension (pulling) force to the right in each case. So the two friction forces are equal.

**Conceptual Question 6.A**

If you press an apple crate against a wall so hard that the crate cannot slide down the wall, what is the direction of (a) the static frictional force $f_s$ on the crate from the wall and (b) the normal force $F_N$ on the crate from the wall. If you increase your push, what happens to (c) $f_s$, (d) $F_N$, and (e) $f_{s,max}$?




**Problem 5.8**

The figure to the right shows the acceleration-versus-force graphs for two objects pulled by rubber bands. What is the mass ratio $m_1/m_2$?

**5.8. Visualize:** Please refer to Figure EX5.8.

**Solve:** Newton's second law is $F = ma$. Applying this to curves 1 at the point $F$ = 3 rubber bands and to curve 2 at the point $F$ = 5 rubber bands gives

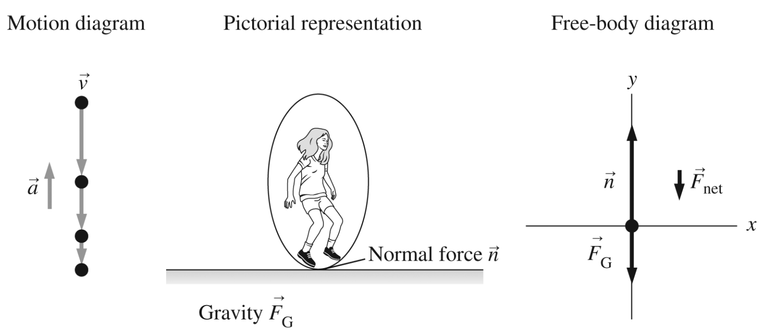
$$\left.\begin{aligned}3F &= m_1(5a_1)\\ 5F &= m_2(4a_1)\end{aligned}\right\} \frac{3}{5} = \frac{5m_1}{4m_2} \quad \Rightarrow \quad \frac{m_1}{m_2} = \frac{12}{25}$$

**Assess:** The line with the steepest slope should have the smallest mass, so we expect $m_1 < m_2$, which is consistent with our calculation.

**Problem 5.48**

You've jumped down from a platform. Your feet are touching the ground and your knees are flexing as you stop. Draw a motion diagram, a force-identification diagram, and a free-body diagram.

**5.48. Visualize:**

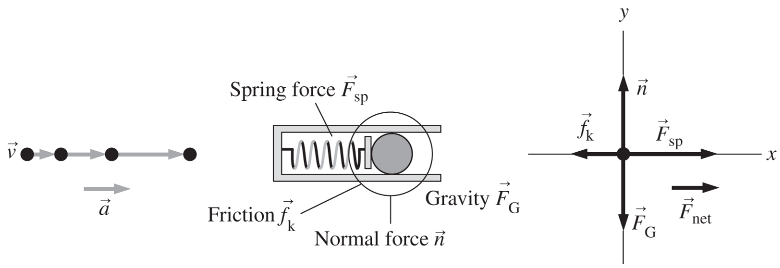



You are going down but accelerating upward.

**Problem 5.51**

A spring-loaded gun shoots a plastic ball. The trigger has just been pulled and the ball is starting to move down the barrel. The barrel is horizontal. Draw a motion diagram, a force-identification diagram, and a free-body diagram.

**5.51. Visualize:**

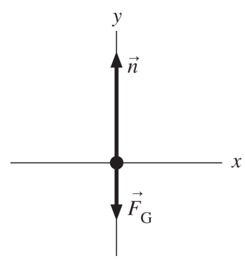



The ball rests on the floor of the barrel because the gravitational force is equal to the normal force. The force of the spring pushes to the right and causes an acceleration to the right.

## Problem 5.53

The leaf hopper, champion jumper of the insect world, can jump straight up at 4 m/s$^2$. The jump itself lasts a mere 1 ms before the insect is clear of the ground. **(a)** Draw a free-body diagram of this mighty leaper while the jump is taking place. **(b)** While the jump is taking place, is the force of the ground on the leaf hopper greater than, less than, or equal to the force of gravity on the leaf hopper? Explain.

**5.53. Visualize:**

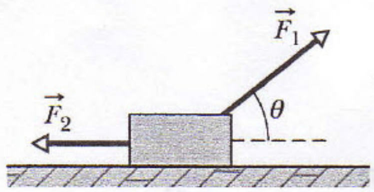


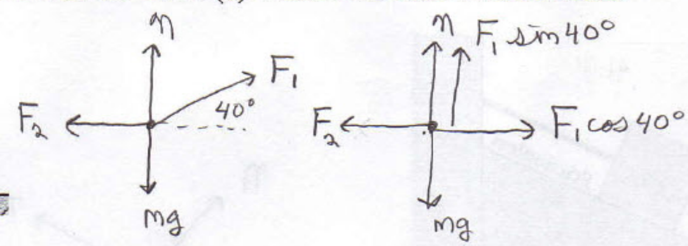

**Solve: (b)** While the leaf hopper is in the act of jumping, it experiences an upward acceleration of 4 m/s$^2$, so the net force acting on it must be upward. Because only the normal force and the force due to gravity are acting in the vertical direction, the normal force from the ground must be greater than the force due to gravity.

## Problem 6.A

In the figure below, two forces, $\vec{F}_1$ and $\vec{F}_2$, act a 50.0 kg crate that sits on a frictionless floor. The magnitude of $F_1$ is 255 N and it is applied at a 40$^{o}$ angle. The magnitude of $F_2$ is 55N. **(a)** What is the normal force exerted on the crate? **(b)** What is the crate's acceleration?

In the figure below, two forces, $\vec{F}_1$ and $\vec{F}_2$, act a 50.0 kg crate that sits on a frictionless floor. The magnitude of $F_1$ is 255 N and it is applied at a 40° angle. The magnitude of $F_2$ is 55N. (a) What is the normal force exerted on the crate? (b) What is the crate's acceleration?




(a) $\sum F_y = ma_y = 0$

$n + F_1 \sin 40° - mg = 0$

$n = mg - F_1 \sin 40°$

$= (50.0\,kg)(9.80\,m/s^2) - (55N)\sin 40° \longrightarrow$ $\boxed{n = 326\,N}$

(b) $\sum F_x = ma_x$

$F_1 \cos 40° - F_2 = ma_x \nearrow$

$a_x = \dfrac{F_1 \cos 40° - F_2}{m}$

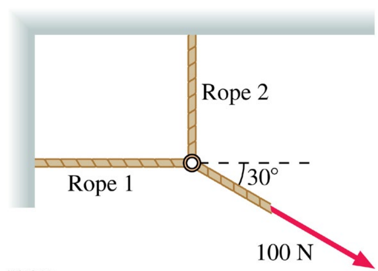
$a_x = \dfrac{(255N)\cos 40° - 55N}{50.0\,Kg}$

$\boxed{a = 2.8\,m/s^2}$

**Problem 4**

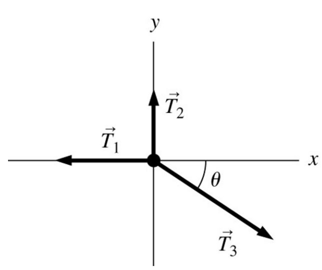
## Problem 6.2

The three ropes in the figure to the right are tied to a small, very light ring. Two of the ropes are anchored to walls at right angles, and the third rope pulls as shown. What are $T_1$ and $T_2$, the magnitudes of the tension forces in the first two ropes.




**6.2. Model:** We can assume that the ring is a single massless particle in static equilibrium.
**Visualize:**

**Pictorial representation**




Known
$T_3 = 100$ N
$\theta = 30°$

Find
$T_1$ $T_2$

**Solve:** Written in component form, Newton's first law is

$$(F_{net})_x = \Sigma F_x = T_{1x} + T_{2x} + T_{3x} = 0\text{ N} \quad (F_{net})_y = \Sigma F_y = T_{1y} + T_{2y} + T_{3y} = 0\text{ N}$$

Evaluating the components of the force vectors from the free-body diagram:

$$T_{1x} = -T_1 \quad T_{2x} = 0\text{ N} \quad T_{3x} = T_3 \cos 30°$$
$$T_{1y} = 0\text{ N} \quad T_{2y} = T_2 \quad T_{3y} = -T_3 \sin 30°$$

Using Newton's first law:

$$-T_1 + T_3 \cos 30° = 0\text{ N} \quad T_2 - T_3 \sin 30° = 0\text{ N}$$

Rearranging:

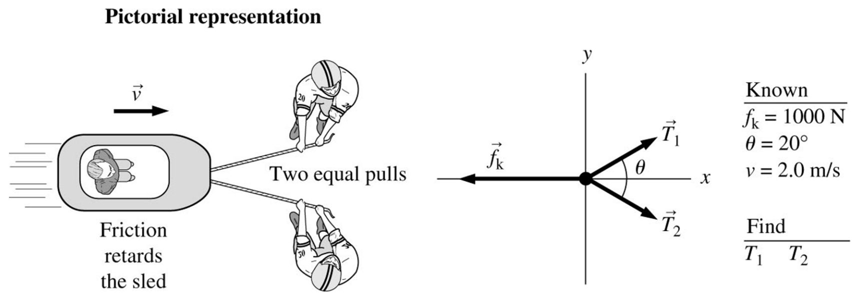
$$T_1 = T_3 \cos 30° = (100\text{ N})(0.8666) = 86.7\text{ N} \quad T_2 = T_3 \sin 30° = (100\text{ N})(0.5) = 50.0\text{ N}$$

**Assess:** Since $\vec{T}_3$ acts closer to the $x$-axis than to the $y$-axis, it makes sense that $T_1 > T_2$.

## Problem 6.3

A football coach sits on a sled while two of his players build their strength by dragging the sled across the field with ropes. The friction force on the sled is 1000 N, the players have equal pulls, and the angle between the two ropes is 20°. How hard must each player pull to drag the coach at a steady 2.0 m/s?

**6.3. Model:** We can assume that the coach and his sled are a particle being towed at a constant velocity by the two ropes, with friction providing the force that resists the pullers.
**Visualize:**




**Solve:** Since the sled is not accelerating, it is in dynamic equilibrium and Newton's first law applies:

$$(F_{net})_x = \Sigma F_x = T_{1x} + T_{2x} + f_{kx} = 0 \text{ N} \quad (F_{net})_y = \Sigma F_y = T_{1y} + T_{2y} + f_{ky} = 0 \text{ N}$$

From the free-body diagram:

$$T_1 \cos\left(\frac{1}{2}\theta\right) + T_2 \cos\left(\frac{1}{2}\theta\right) - f_k = 0 \text{ N} \quad T_1 \sin\left(\frac{1}{2}\theta\right) - T_2 \sin\left(\frac{1}{2}\theta\right) + 0 \text{ N} = 0 \text{ N}$$

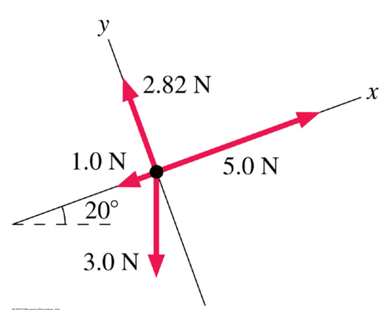
From the second of these equations $T_1 = T_2$. Then from the first:

$$2T_1 \cos 10° = 1000 \text{ N} \Rightarrow T_1 = \frac{1000 \text{ N}}{2\cos 10°} = \frac{1000 \text{ N}}{1.970} = 508 \text{ N} \approx 510 \text{ N}$$

**Assess:** The two tensions are equal, as expected, since the two players are pulling at the same angle. The two add up to only slightly more than 1000 N, which makes sense because the angle at which the two players are pulling is small.

## Problem 6.9

The forces in the figure to the right act on a 2.0 kg object. What are the values of $a_x$ and $a_y$, the x- and y-components of the object's acceleration?




**6.9. Solve:** Three of the vectors lie along the axes of the tilted coordinate system. Notice that the angle between the 3 N force and the $-y$-axis is the same 20° by which the coordinates are tilted. Applying Newton's second law,

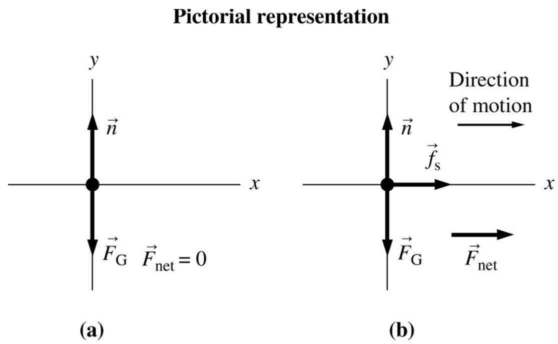
$$a_x = \frac{(F_{net})_x}{m} = \frac{5.0 \text{ N} - 1.0 \text{ N} - (3.0\sin 20°) \text{ N}}{2.0 \text{ kg}} = 1.49 \text{ m/s}^2 \approx 1.5 \text{ m/s}^2$$

$$a_y = \frac{(F_{net})_y}{m} = \frac{2.82 \text{ N} - (3.0\cos 20°) \text{ N}}{2.0 \text{ kg}} = 0 \text{ m/s}^2$$

## Problem 6.26

A 10 kg crate is placed on a horizontal conveyor belt. The materials are such that $\mu_s = 0.50$ and $\mu_k = 0.30$. **(a)** Draw a free-body diagram showing all the forces on the crate if the conveyor belt runs at constant speed? **(b)** Draw a free-body diagram showing all the forces on the crate if the conveyor belt is speeding up? **(c)** What is the maximum acceleration the belt can have without the crate slipping?

**6.26. Model:** We will represent the crate as a particle.
**Visualize:**




**Solve: (a)** When the belt runs at constant speed, the crate has an acceleration $\vec{a}=\vec{0}$ m/s$^2$ and is in dynamic equilibrium. Thus $\vec{F}_{net}=\vec{0}$. It is tempting to think that the belt exerts a friction force on the crate. But if it did, there would be a *net* force because there are no other possible horizontal forces to balance a friction force. Because there is no net force, there cannot be a friction force. The only forces are the upward normal force and the gravitational force on the crate. (A friction force would have been needed to get the crate moving initially, but no horizontal force is needed to keep it moving once it is moving with the same constant speed as the belt.)
**(b)** If the belt accelerates gently, the crate speeds up without slipping on the belt. Because it is accelerating, the crate must have a net horizontal force. So *now* there is a friction force, and the force points in the direction of the crate's motion. Is it static friction or kinetic friction? Although the crate is moving, there is *no* motion of the crate relative to the belt. Thus, it is a *static* friction force that accelerates the crate so that it moves without slipping on the belt.
**(c)** The static friction force has a maximum possible value $(f_s)_{max}=\mu_s n.$ The maximum possible acceleration of the crate is

$$a_{max}=\frac{(f_s)_{max}}{m}=\frac{\mu_s n}{m}$$

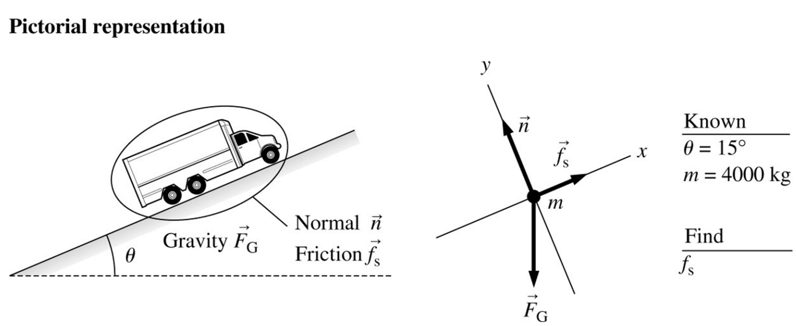
If the belt accelerates more rapidly than this, the crate will not be able to keep up and will slip. It is clear from the free-body diagram that $n=F_G=mg$. Thus,

$$a_{max}=\mu_s g=(0.5)(9.80\text{ m/s}^2)=4.9\text{ m/s}^2$$

## Problem 6.29

A 4000 kg truck is parked on a 15° slope. How big is the friction force on the truck? The coefficient of static friction between the tires and the road is 0.90.

**6.29. Model:** We assume that the truck is a particle in equilibrium, and use the model of static friction.
**Visualize:**




**Solve:** The truck is not accelerating, so it is in equilibrium, and we can apply Newton's first law. The normal force has no component in the $x$-direction, so we can ignore it here. For the other two forces:

$$(F_{net})_x=\Sigma F_x=f_s-(F_G)_x=0\text{ N}\Rightarrow f_s=(F_G)_x=mg\sin\theta=(4000\text{ kg})(9.8\text{ m/s}^2)(\sin 15°)=10{,}145\text{ N}\approx 10{,}000\text{ N}$$

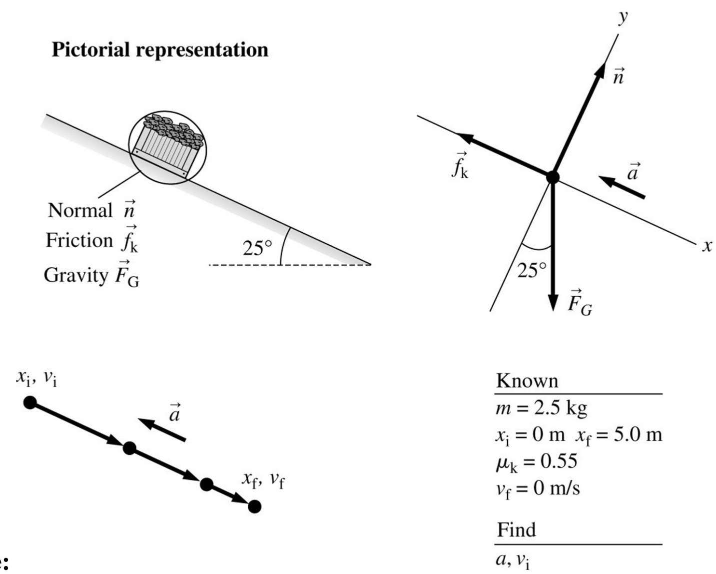
**Assess:** The truck's weight ($mg$) is roughly 40,000 N. A friction force that is $\approx$25, of the truck's weight seems reasonable.

## Problem 6.32

You and your friend Peter are putting new shingles on a roof pitched at 25°. You're sitting on the very top of the roof when Peter, who is at the edge of the roof directly below you, 5.0 m away, asks you for of the box of nails. Rather than carry the 2.5 kg box of nails down to Peter, you decide to give the box of push and have it slide down to him. If the coefficient of kinetic friction between the box and the roof is 0.55, with what speed should you push the box to have it gently come to rest right at the edge of the roof.

**6.32. Model:** The box of shingles is a particle subject to Newton's laws and kinematics.

**Visualize:**




**Solve:** Newton's laws can be used in the coordinate system in which the direction of motion of the box of shingles defines the $+x$-axis. The angle that $\vec{F}_G$ makes with the $-y$-axis is 25°.

$$(\Sigma F)_x = F_G \sin 25° - f_k = ma$$

$$(\Sigma F)_y = n - F_G \cos 25° = 0 \Rightarrow n = F_G \cos 25°$$

We have used the observation that the shingles do not leap off the roof, so the acceleration in the $y$-direction is zero. Combining these equations with $f_k = \mu_k n$ and $F_G = mg$ yields

$$mg \sin 25° - \mu_k mg \cos 25° = ma$$

$$\Rightarrow a = (\sin 25° - \mu_k \cos 25°)g = -0.743 \text{ m/s}^2$$

where the minus sign indicates the acceleration is directed up the incline. The required initial speed to have the box come to rest after 5.0 m is found from kinematics.

$$v_f^2 = v_i^2 + 2a\Delta x \Rightarrow v_i^2 = -2(-0.743 \text{ m/s}^2)(5.0 \text{ m}) \Rightarrow v_i = 2.7 \text{ m/s}$$

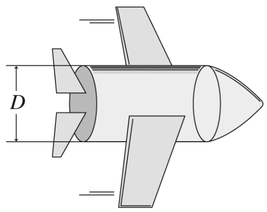
**Assess:** To give the shingles an initial speed of 2.7 m/s requires a strong, determined push, but is not beyond reasonable.

## Problem 6.34

A medium-sized jet has a 3.8-m-diameter fuselage and a loaded mass of 85,000 kg. The drag on an airplane is primarily due to the cylindrical fuselage, and the aerodynamic shaping gives it a drag coefficient of 0.37. How much thrust must the jet's engines provide to cruise at 230 m/s at an altitude where the air density is 1.0 kg/m$^3$?

**6.34. Model:** Ignore the drag on the wings and focus on the cylindrical fuselage.

**Visualize:** The net force is zero as the jet cruises at 230 m/s, so the thrust must be equal in magnitude to the drag. The gravitational and lift forces are equal in magnitude and opposite in direction.




Known

$D = 3.8$ m $\Rightarrow r = 1.9$ m

$C = 0.37$

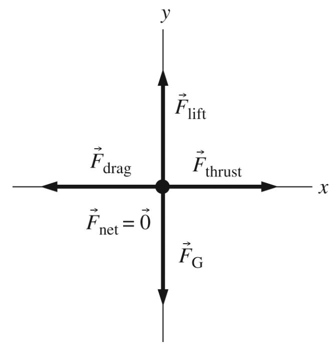
$\rho = 1.0$ kg/m$^3$

$v = 230$ m/s

$m = 85{,}000$ kg

Find

$F_{thrust}$



**Solve:**

$$F_{\text{thrust}} = F_{\text{drag}} = \frac{1}{2}C\rho A v^2 = \frac{1}{2}(0.37)(1.0\ \text{kg/m}^3)[\pi(1.9\ \text{m})^2](230\ \text{m/s})^2 = 110\ \text{kN}$$

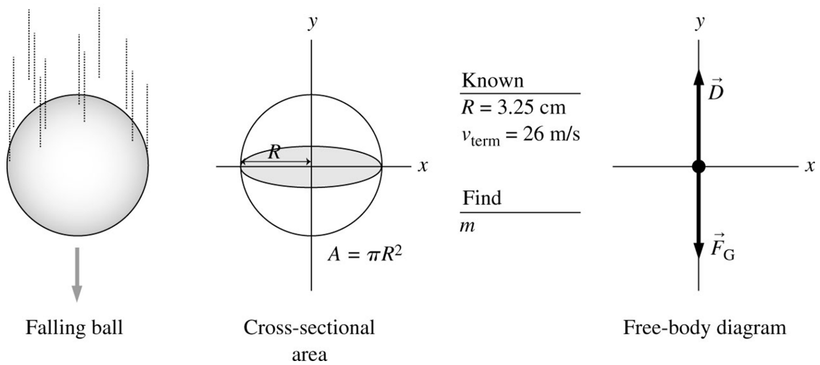
**Assess:** The thrust force must be large, but it is within the capability of jet engines.

## Problem 6.36

A 6.5-cm-diameter ball has a terminal speed of 26 m/s. What is the balls mass?

**6.36. Model:** We will represent the tennis ball as a particle. The drag coefficient is 0.5.
**Visualize:**

**Pictorial representation**




The tennis ball falls straight down toward the earth's surface. The ball is subject to a net force that is the resultant of the gravitational and drag force vectors acting vertically, in the downward and upward directions, respectively. Once the net force acting on the ball becomes zero, the terminal velocity is reached and remains constant for the rest of the motion.
**Solve:** The mathematical equation defining the dynamical equilibrium situation for the falling ball is

$$\vec{F}_{\text{net}} = \vec{F}_{\text{G}} + \vec{D} = \vec{0}\ \text{N}$$

Since only the vertical direction matters, one can write:

$$\Sigma F_y = 0\ \text{N} \Rightarrow \quad F_{\text{net}} = D - F_{\text{G}} = 0\ \text{N}$$

When this condition is satisfied, the speed of the ball becomes the constant terminal speed $v = v_{\text{term}}$. The magnitudes of the gravitational and drag forces acting on the ball are:

$$F_{\text{G}} = mg = m(9.80\ \text{m/s}^2)$$

$$D \approx \frac{1}{2}(C\rho A v_{\text{term}}^2) = 0.5(0.5)(1.2\ \text{kg/m}^3)(\pi R^2)v_{\text{term}}^2 = (0.3\pi)(0.0325\ \text{m})^2(26\ \text{m/s})^2 = 0.67\ \text{N}$$

The condition for dynamic equilibrium becomes:

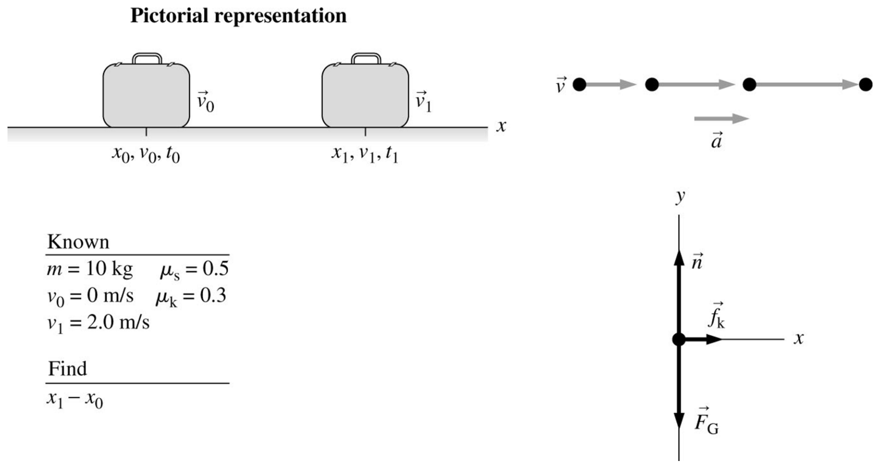
$$(9.80\ \text{m/s}^2)m - 0.67\ \text{N} = 0\ \text{N} \Rightarrow m = \frac{0.67\ \text{N}}{9.80\ \text{m/s}^2} = 69\ \text{g}$$

**Assess:** The value of the mass of the tennis ball obtained above seems reasonable.

## Problem 6.50

A baggage handler drops your 10 kg suitcase onto a conveyor belt running at 2.0 m/s. The materials are such that $\mu_s = 0.50$ and $\mu_k = 0.30$. How far is your suitcase dragged before it is riding smoothly on the belt?

**6.50. Model:** We assume the suitcase is a particle accelerating horizontally under the influence of friction only.
**Visualize:**




**Solve:** Because the conveyor belt is already moving, friction drags your suitcase to the right. It will accelerate until it matches the speed of the belt. We need to know the horizontal acceleration. Since there's no acceleration in the vertical direction, we can apply Newton's first law to find the normal force:

$$n = F_G = mg = (10\text{ kg})(9.80\text{ m/s}^2) = 98.0\text{ N}$$

The suitcase is accelerating, so we use $\mu_k$ to find the friction force

$$f_k = \mu_k mg = (0.3)(98.0\text{ N}) = 29.4\text{ N}$$

We can find the horizontal acceleration from Newton's second law:

$$(F_{net})_x = \Sigma F_x = f_k = ma \Rightarrow a = \frac{f_k}{m} = \frac{29.4\text{ N}}{10\text{ kg}} = 2.94\text{ m/s}^2$$

From one of the kinematic equations:

$$v_1^2 = v_0^2 + 2a(x_1 - x_0) \Rightarrow x_1 - x_0 = \frac{v_1^2 - v_0^2}{2a} = \frac{(2.0\text{ m/s})^2 - (0\text{ m/s})^2}{2(2.94\text{ m/s}^2)} = 0.68\text{ m}$$

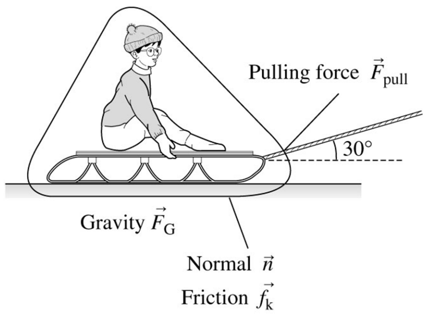
The suitcase travels 0.68 m before catching up with the belt and riding smoothly.
**Assess:** If we imagine throwing a suitcase at a speed of 2.0 m/s onto a motionless surface, 0.68 m seems a reasonable distance for it to slide before stopping.

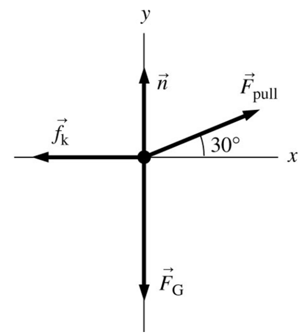
## Problem 6.52

It's a snowy day and you're pulling a friend along a level road on a sled. You've both been taking physics, so she asks what you think the coefficient of friction between the sled and the snow is. You've been walking at a steady 1.5 m/s, and the rope pulls up on the sled at a 30º angle. You estimate that the mass of the sled, with your friend on it, is 60 kg and that you're pulling with a force of 75 N. **(a)** What answer will you give? **(b)** Does the calculated coefficient of friction reasonable? Explain.

**6.52. Model:** We will model the sled and friend as a particle, and use the model of kinetic friction because the sled is in motion.
**Visualize:**

**Pictorial representation**




The net force on the sled is zero (note the constant speed of the sled). That means the component of the pulling force along the +$x$-direction is equal to the magnitude of the kinetic force of friction in the −$x$-direction. Also note that $(F_{net})_y = 0$ N, since the sled is not moving along the $y$-axis.

**Solve:** Newton's second law is

$$(F_{net})_x = \Sigma F_x = n_x + (F_G)_x + (f_k)_x + (F_{pull})_x = 0\text{ N} + 0\text{ N} - f_k + F_{pull}\cos\theta = 0\text{ N}$$

$$(F_{net})_y = \Sigma F_y = n_y + (F_G)_y + (f_k)_y + (F_{pull})_y = n - mg + 0\text{ N} + F_{pull}\sin\theta = 0\text{ N}$$

The $x$-component equation using the kinetic friction model $f_k = \mu_k n$ reduces to

$$\mu_k n = F_{pull}\cos\theta$$

The $y$-component equation gives

$$n = mg - F_{pull}\sin\theta$$

We see that the normal force is smaller than the gravitational force because $F_{pull}$ has a component in a direction opposite to the direction of the gravitational force. In other words, $F_{pull}$ is partly lifting the sled. From the $x$-component equation, $\mu_k$ can now be obtained as

$$\mu_k = \frac{F_{pull}\cos\theta}{mg - F_{pull}\sin\theta} = \frac{(75\text{ N})(\cos 30°)}{(60\text{ kg})(9.80\text{ m/s}^2) - (75\text{ N})(\sin 30°)} = 0.12$$

**Assess:** A quick glance at the various $\mu_k$ values in Table 6.1 suggests that a value of 0.12 for $\mu_k$ is reasonable.