

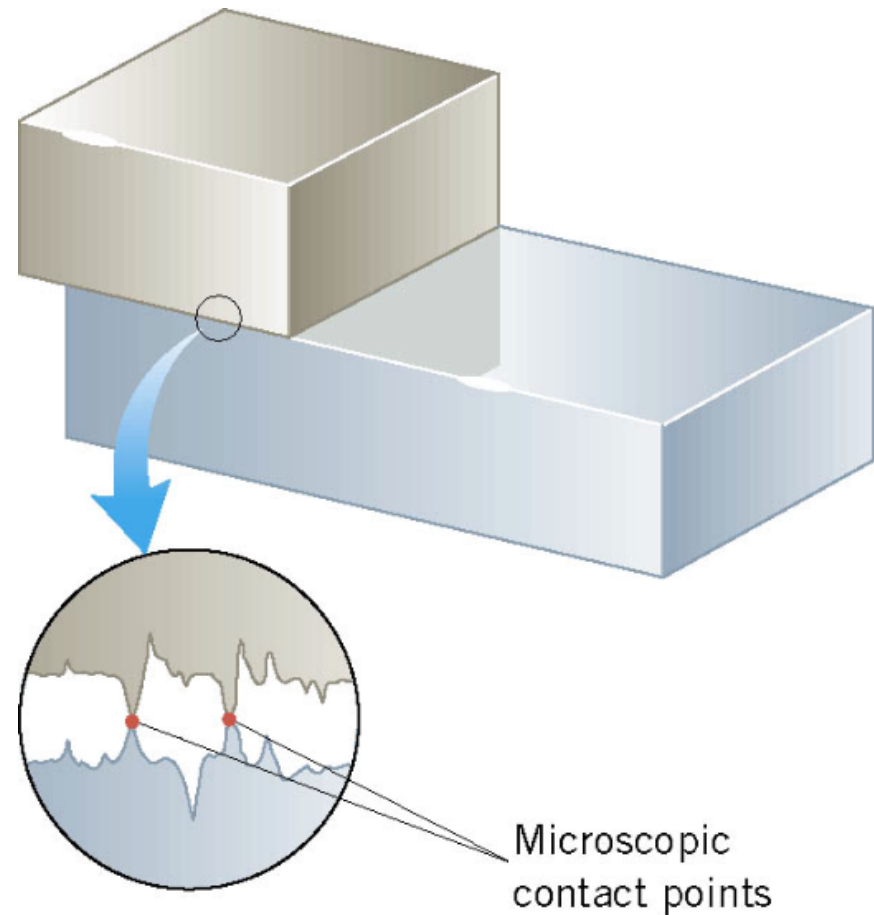
# *Chapter 4*

## ***Forces and Newton's Laws of Motion***

*continued*

## 4.9 Static and Kinetic Frictional Forces

When an object is in contact with a surface forces can act on the objects. The component of this force acting on each object that is parallel to the surface is called the ***frictional force***.



## 4.9 Static and Kinetic Frictional Forces

When the two surfaces are not sliding (at rest) across one another the friction is called **static friction**.

Block is at rest. Net force action on block

$$\sum \mathbf{F} = \vec{\mathbf{F}}_R + \vec{\mathbf{f}}_s = 0$$

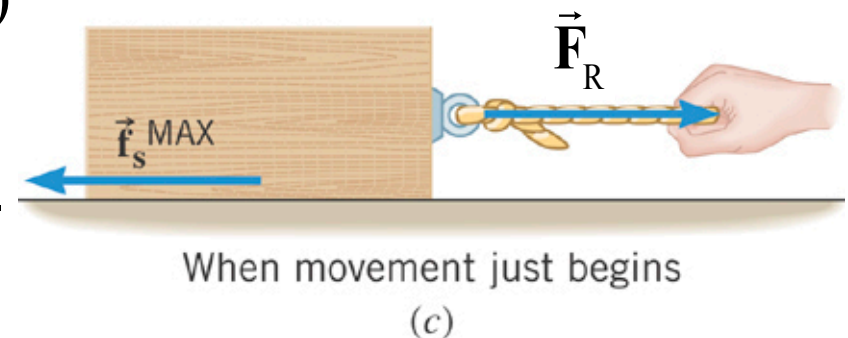
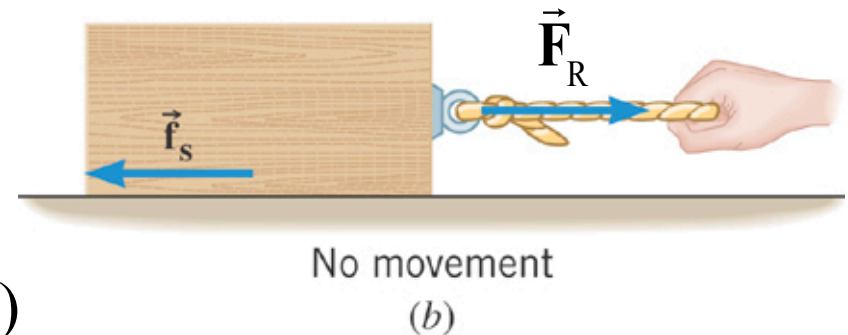
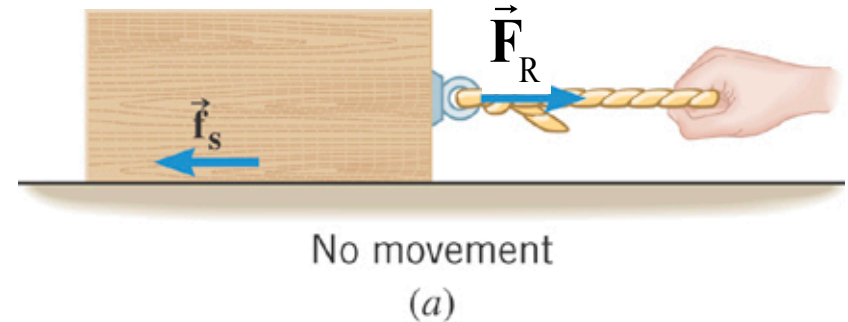
$$+F_R + (-f_s) = 0 \text{ (directions are opposite)}$$

$$F_R = f_s \text{ (magnitudes the same)}$$

The harder the person pulls on the rope the larger the static frictional force becomes.

Until the static frictional force  $f_s$  reaches its maximum value,  $f_s^{\text{Max}}$ , and the block begins to slide.

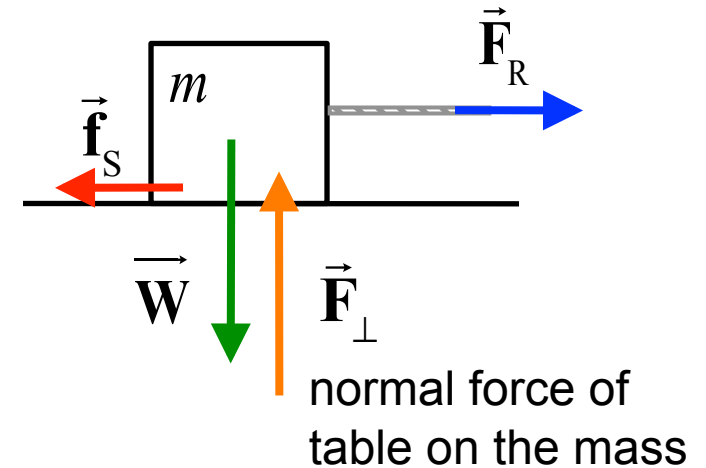
$\vec{\mathbf{F}}_R$  = rope force



## 4.9 Static and Kinetic Frictional Forces

The magnitude of the static frictional force can have any value from zero up to a maximum value,  $f_s^{\text{Max}}$

Friction equations are for MAGNITUDES only.



$$f_s \leq f_s^{\text{Max}} \quad (\text{object remains at rest})$$

$$f_s^{\text{Max}} = \mu_s F_\perp,$$

$$0 < \mu_s < 1$$

$\mu_s$  , coefficient of static friction.

With no other vertical forces,  
 $F_\perp = W = mg$

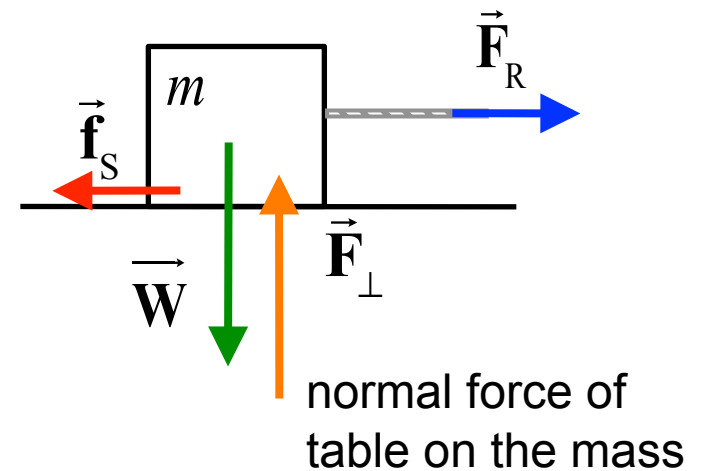
**Example:** It takes a horizontal force of at least 10,000 N to begin to move a 5,000 kg mass on flat road. What is the coefficient of friction between the two surfaces?

$$W = mg = 49,000\text{N}$$

$$f_S^{\text{Max}} = 10,000 \text{ N.}$$

$$f_S^{\text{Max}} = \mu_S F_{\perp} = \mu_S W$$

$$\Rightarrow \mu_S = f_S^{\text{Max}} / W = \underline{0.20}$$



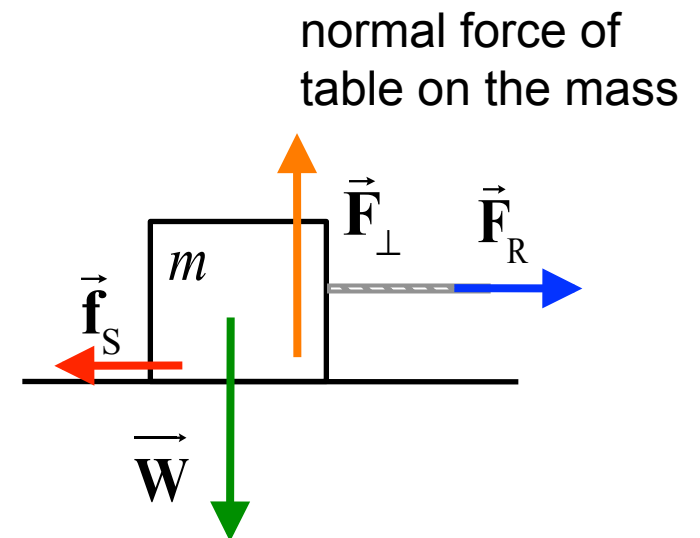
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### Clicker Question 4.10

$$f_S^{\text{MaX}} = \mu_S F_{\perp}$$

**A 50 kg mass is at rest on a table, where the coefficient of friction,  $\mu_s = 0.5$ . What is the lowest horizontal force that will get the mass to begin to move?**

- a) 25 N
- b) 50 N
- c) 250 N
- d) 500 N
- e) 1000 N

## Clicker Question 4.10

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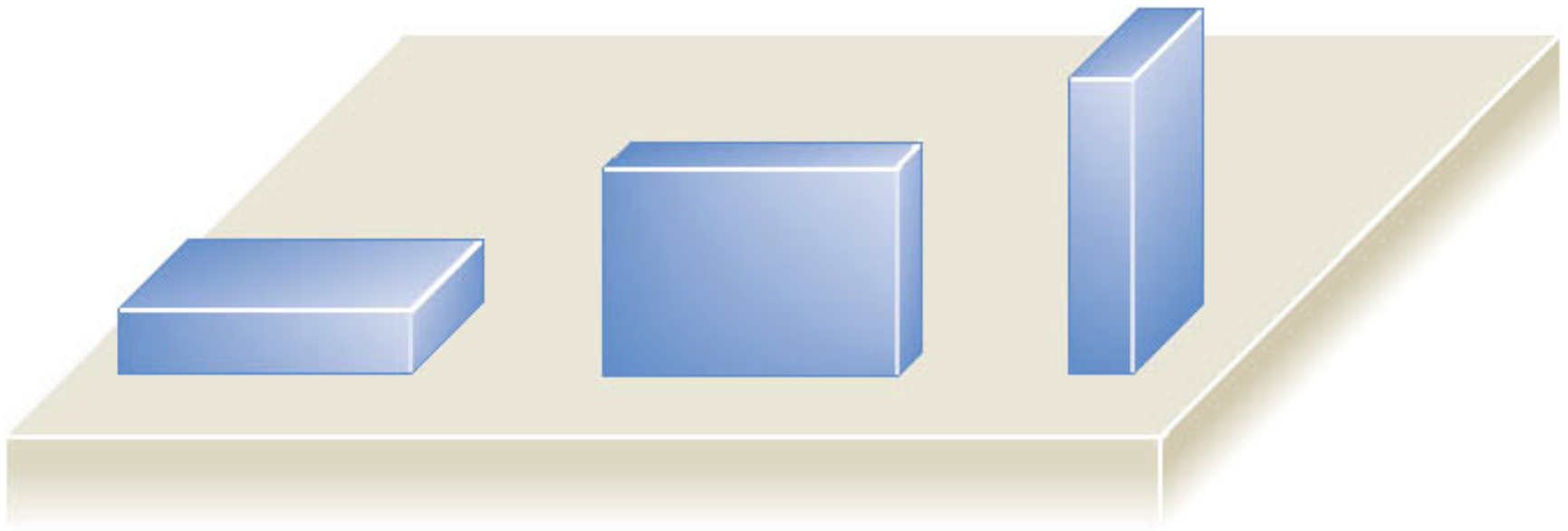
e) 1000 N

$$\begin{aligned} f_s^{\text{Max}} &= \mu_s F_{\perp} = \mu_s W \\ &= 0.5(mg) = 0.5(50\text{kg})(9.80 \text{ m/s}^2) \\ &= 250 \text{ N} \end{aligned}$$



## 4.9 *Static and Kinetic Frictional Forces*

Note that the magnitude of the frictional force does not depend on the contact area of the surfaces.



## 4.9 Static and Kinetic Frictional Forces

**Static friction** opposes the *impending* relative motion between two objects.

**Kinetic friction** opposes the relative sliding motion motions that actually does occur.

Kinetic friction

$$f_k = \mu_k F_{\perp}$$

Friction equations are  
for MAGNITUDES only.

$0 < \mu_k < 1$  is called the coefficient  
of kinetic friction.

$\vec{f}_k$  is a horizontal force.

$\vec{F}_{\perp}$  is a vertical force.

OK because friction equations are  
for MAGNITUDES only.

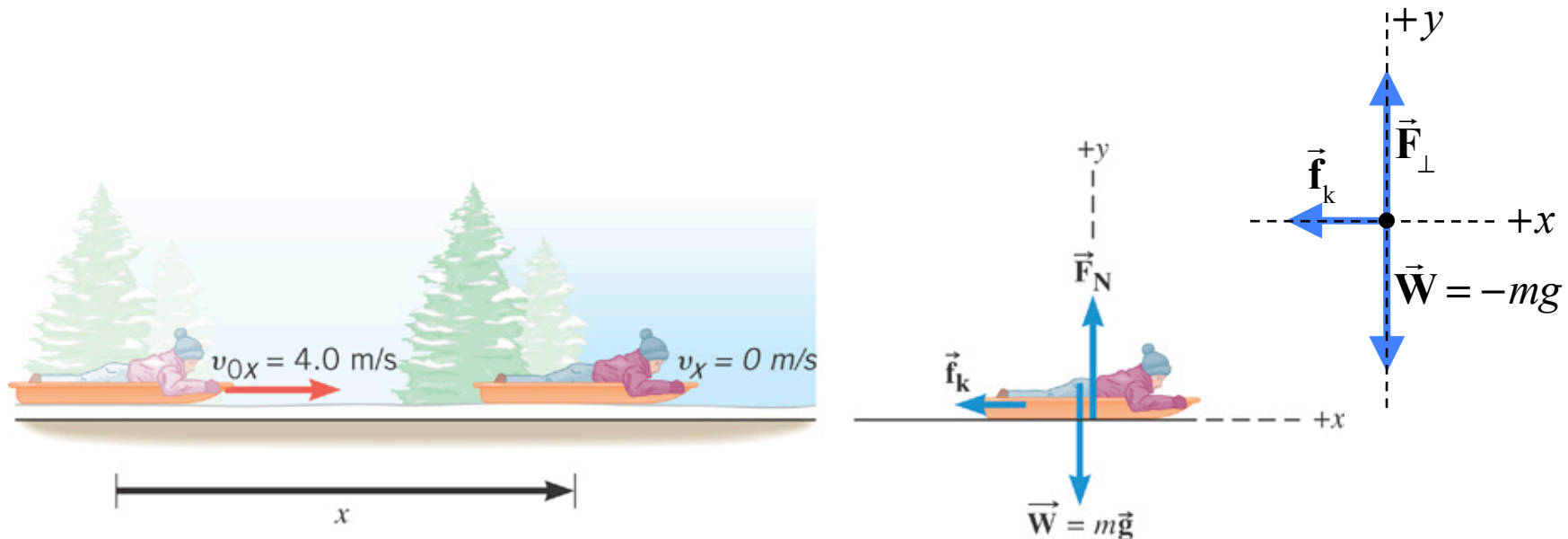
## 4.9 Static and Kinetic Frictional Forces

**Table 4.2** Approximate Values of the Coefficients of Friction for Various Surfaces\*

Materials	Coefficient of Static Friction, $\mu_s$	Coefficient of Kinetic Friction, $\mu_k$
Glass on glass (dry)	0.94	0.4
Ice on ice (clean, 0 °C)	0.1	0.02
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on ice	0.1	0.05
Steel on steel (dry hard steel)	0.78	0.42
Teflon on Teflon	0.04	0.04
Wood on wood	0.35	0.3

\*The last column gives the coefficients of kinetic friction, a concept that will be discussed shortly.

## 4.9 Static and Kinetic Frictional Forces

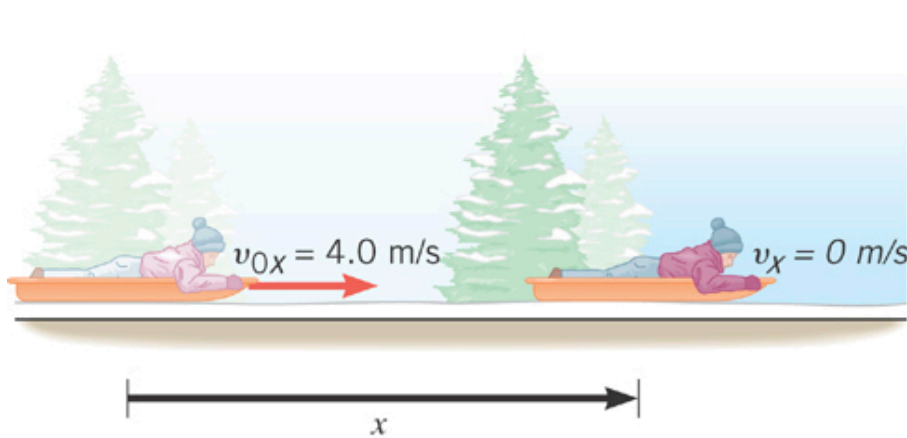


(a)

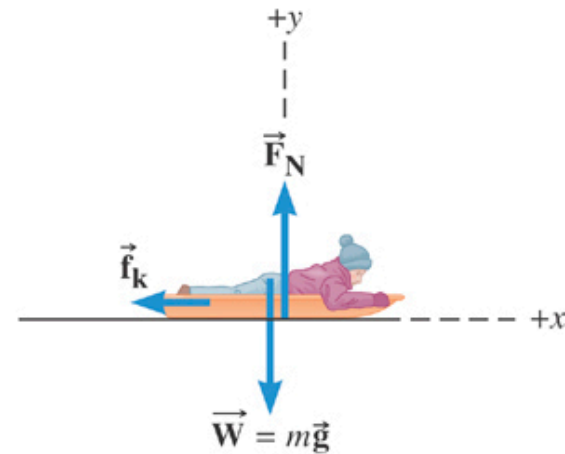
Showing just the forces acting on **one object** is called a “Free Body Diagram”

The sled comes to a halt because the kinetic frictional force opposes its motion and causes the sled to slow down.

## 4.9 Static and Kinetic Frictional Forces



(a)



(b) Free-body diagram  
for the sled and rider

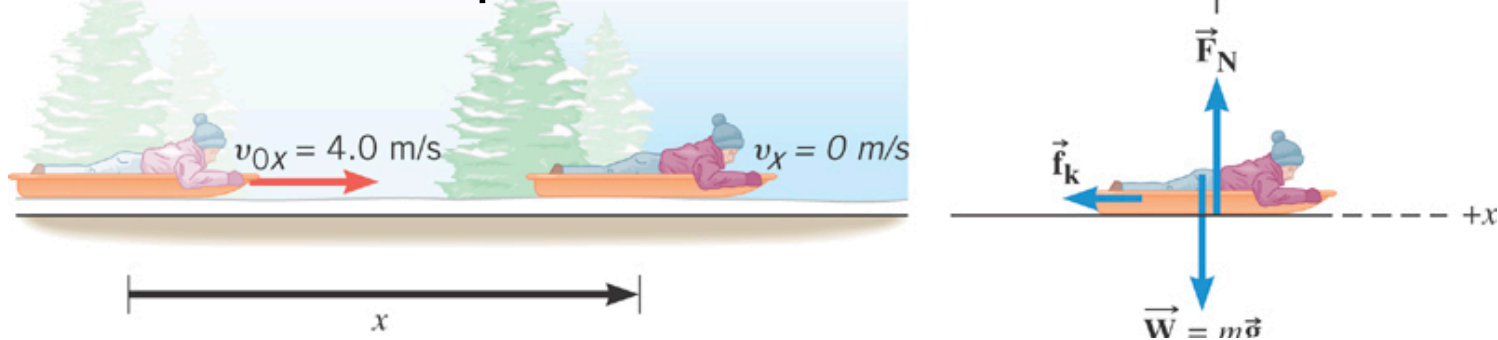
Suppose the coefficient of kinetic friction is 0.05 and the total mass is 40kg. What is the kinetic frictional force?

Friction equations are for MAGNITUDES only.

$$f_k = \mu_k F_N$$
$$= \mu_k mg = 0.05(40\text{kg})(9.80\text{m/s}^2) = 20\text{N}$$

### Clicker Question 4.11

The sled comes to a halt because the kinetic frictional force opposes its motion and causes the sled to slow down from the initial speed of  $+4.0 \text{ m/s}$  to zero.



If the magnitude of the kinetic frictional force,  $f_k = 20 \text{ N}$ , and the total mass is  $40 \text{ kg}$ , **how far does the sled travel?**

- a)  $2 \text{ m}$
- b)  $4 \text{ m}$
- c)  $8 \text{ m}$
- d)  $16 \text{ m}$
- e)  $32 \text{ m}$

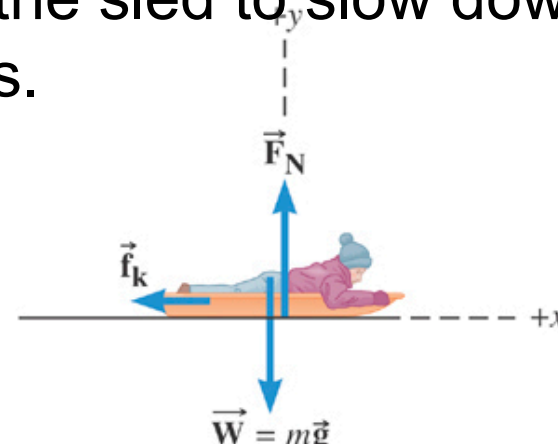
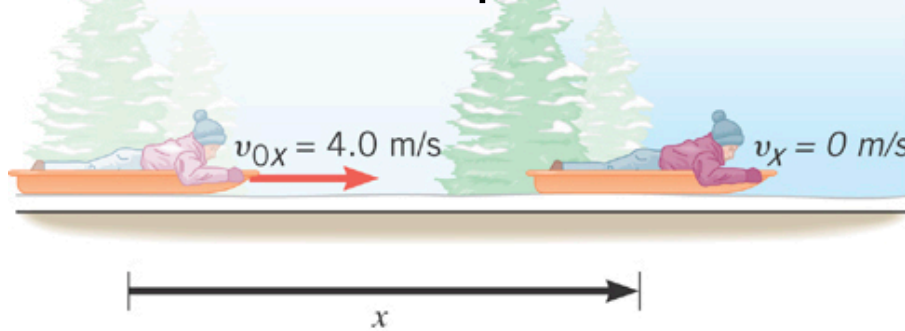
#### Hints

vector  $f_k = -20 \text{ N}$

use  $v^2 = v_{0x}^2 + 2ax$

### Clicker Question 4.11

The sled comes to a halt because the kinetic frictional force opposes its motion and causes the sled to slow down from from the initial speed of +4.0 m/s.



If the magnitude of the kinetic frictional force,  $f_k = 20\text{N}$ , and the total mass is 40kg, **how far does the sled travel?**

a) 2m

b) 4m

c) 8m

d) 16m

e) 32m

$$v^2 = v_{0x}^2 + 2ax$$

$$a = \frac{f_k}{m} = \frac{-20\text{N}}{40\text{kg}} = -0.5 \text{ m/s}^2$$

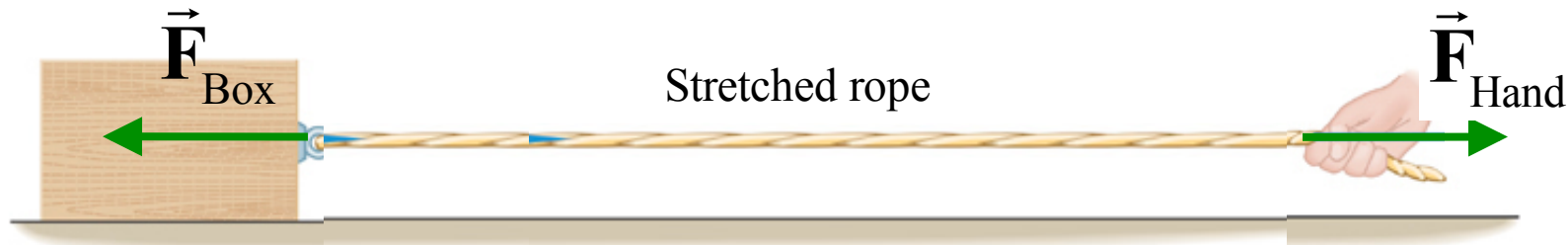
$$x = \frac{-v_{0x}^2}{2a} = \frac{-16\text{m}^2/\text{s}^2}{2(-0.5 \text{ m/s}^2)} = +16\text{m}$$

#### 4.10 The Tension Force

Cables and ropes transmit forces through **tension**.

Box surface force  
acting on the rope

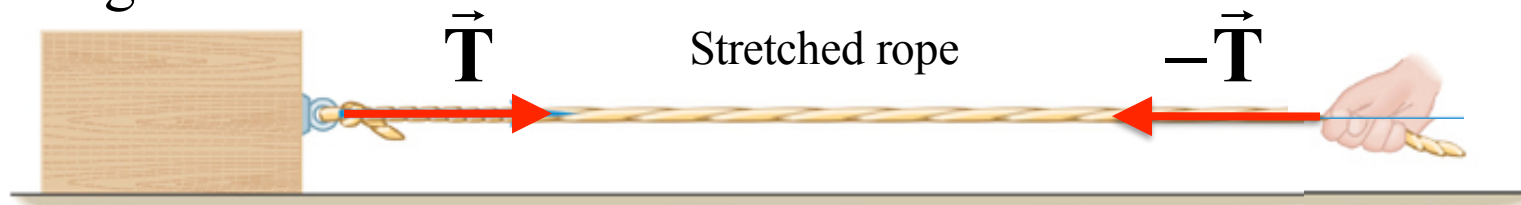
Hand force  
acting on the rope



(b)

Rope tension force  
acting on the box

Rope tension force  
acting on the hand



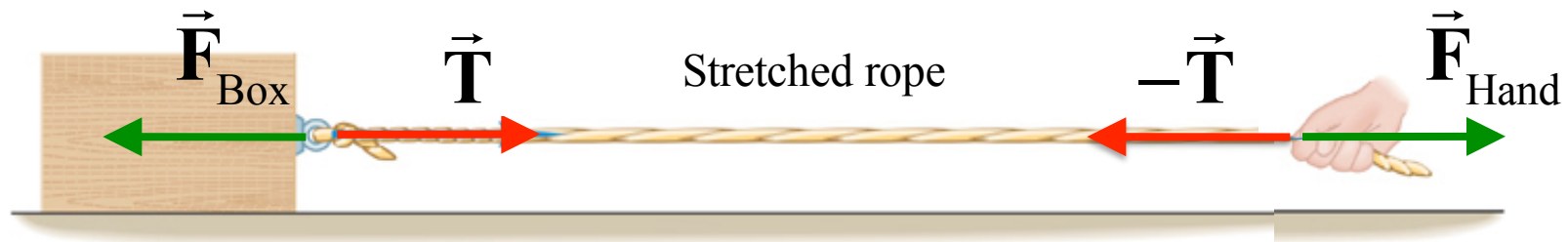
$(\vec{F}_{\text{Box}}, \vec{T})$  These are Newton's 3<sup>rd</sup> law Action – Reaction pairs  $(-\vec{T}, \vec{F}_{\text{Hand}})$

magnitudes:  $T = F_{\text{Hand}}$



## 4.10 The Tension Force

Hand force stretches the rope that generates tension forces at the ends of the rope



$$(\vec{F}_{\text{Box}}, \vec{T})$$

These are Newton's 3<sup>rd</sup> law  
Action – Reaction pairs

$$(\vec{F}_{\text{Hand}}, -\vec{T})$$

Tension pulls on box

Box pulls on rope

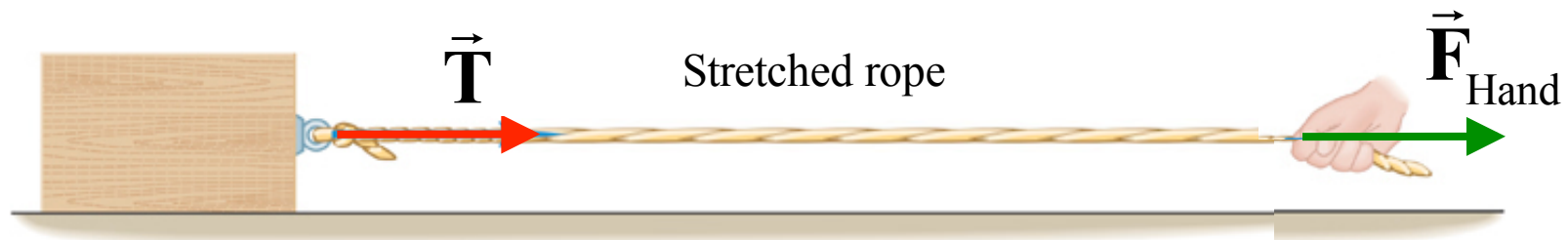
Tension pulls on hand

Hand pulls on rope

#### 4.10 The Tension Force

Cables and ropes transmit forces through ***tension***.

These are the important forces



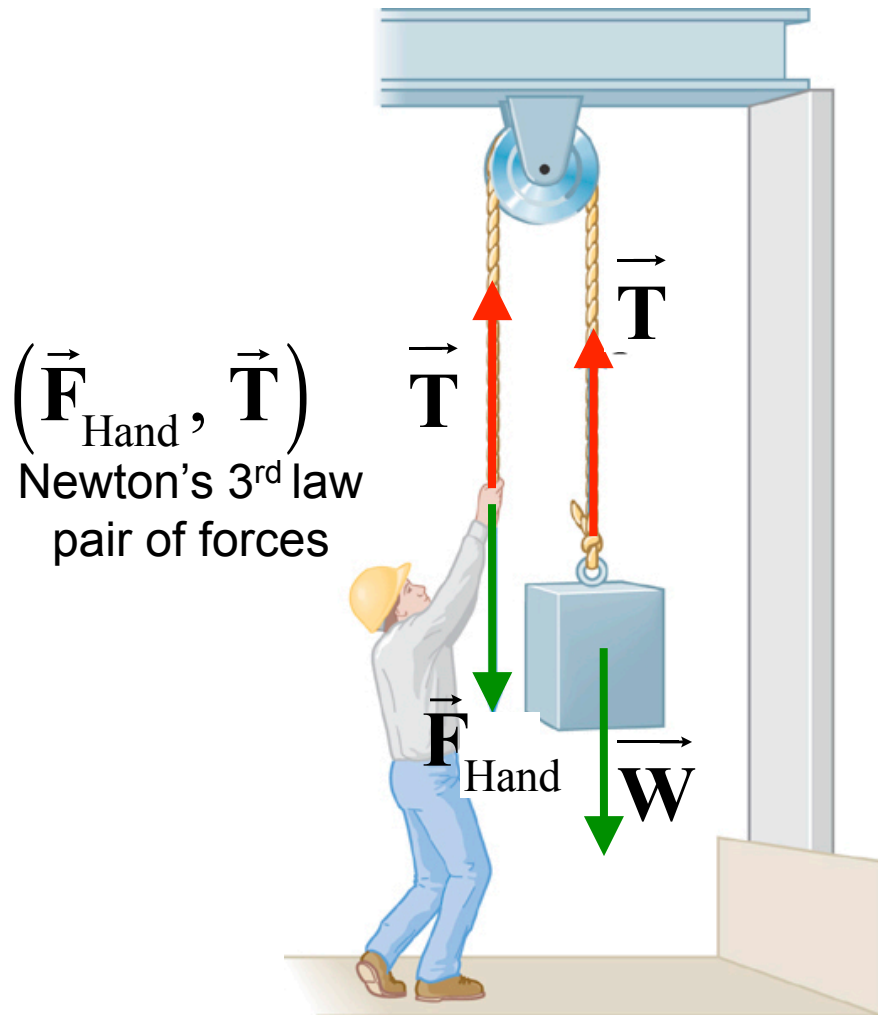
Hand force causes a tension force on the box

Force magnitudes are the same

$$T = F_{\text{Hand}}$$

## 4.10 The Tension Force

Corrected Figure 4.26



A massless rope will transmit tension magnitude undiminished from one end to the other.

A massless, frictionless pulley, transmits the tension undiminished to the other end.

If the mass is at rest or moving with a constant speed & direction the Net Force on the mass is zero!

$$\sum \vec{F} = \vec{W} + \vec{T} = 0$$

$$0 = -mg + \vec{T}$$

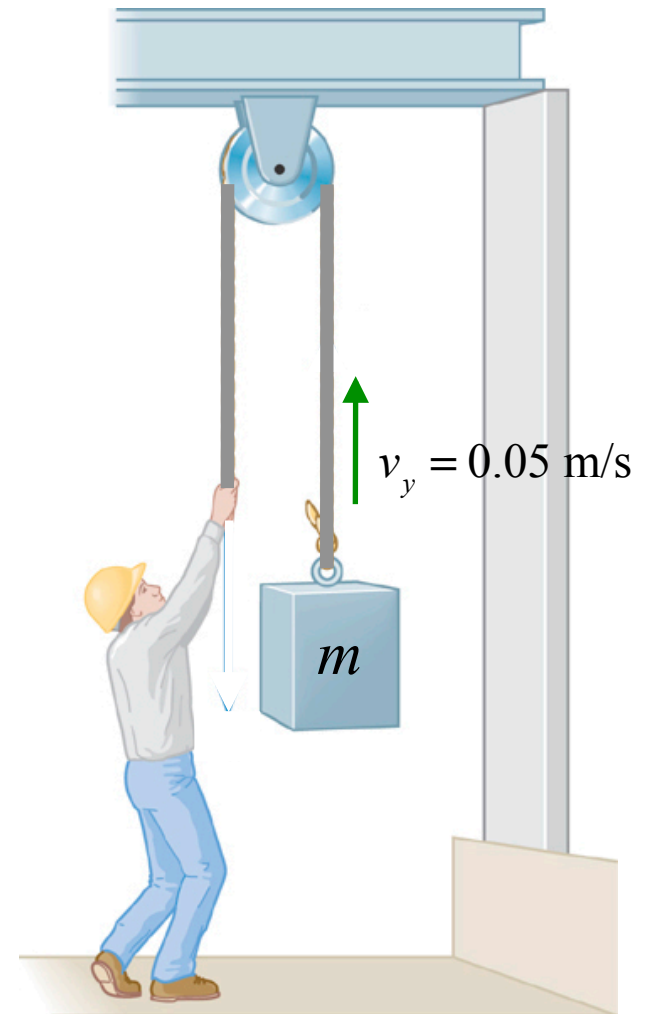
$$\vec{T} = +mg, \text{ and } \vec{F}_{\text{Hand}} = -mg$$

Note: the weight of the man must be larger than the weight of the box, or the mass will drop and the tension force will accelerate the man upward.

### Clicker Question 4.12

The person is raising a mass  $m$  at a constant speed of  $0.05 \text{ m/s}$ . What force must the man apply to the rope to maintain the upward speed of the mass.

- a)  $mg$
- b)  $> mg$
- c)  $< mg$
- d)  $m(0.05 \text{ m/s})$
- e)  $mg + m(0.05 \text{ m/s})$



## Clicker Question 4.12

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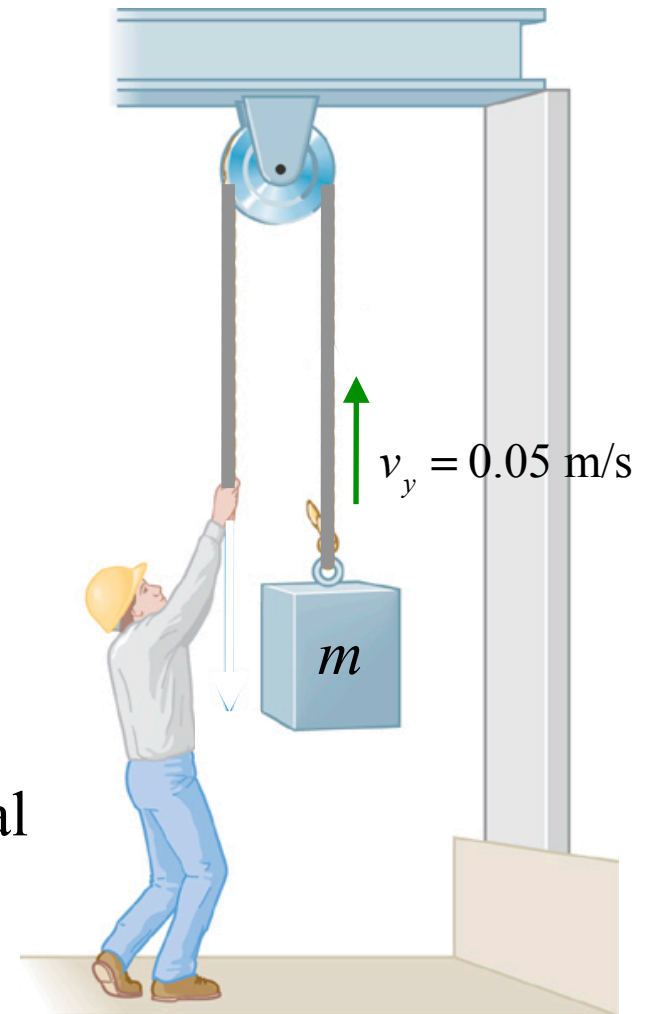
c)  $< mg$

d)  $m(0.05 \text{ m/s})$

e)  $mg + m(0.05 \text{ m/s})$

Constant speed and direction  $\Leftrightarrow$  no net force.

The person must apply a force to the rope equal to the weight of the mass  $= mg$ .



#### 4.11 *Equilibrium Application of Newton's Laws of Motion*

## Definition of Equilibrium

An object is in equilibrium when it has zero acceleration.

$$\sum F_x = 0$$

$$\sum F_y = 0$$

We have been using this concept for the entire Chapter 4

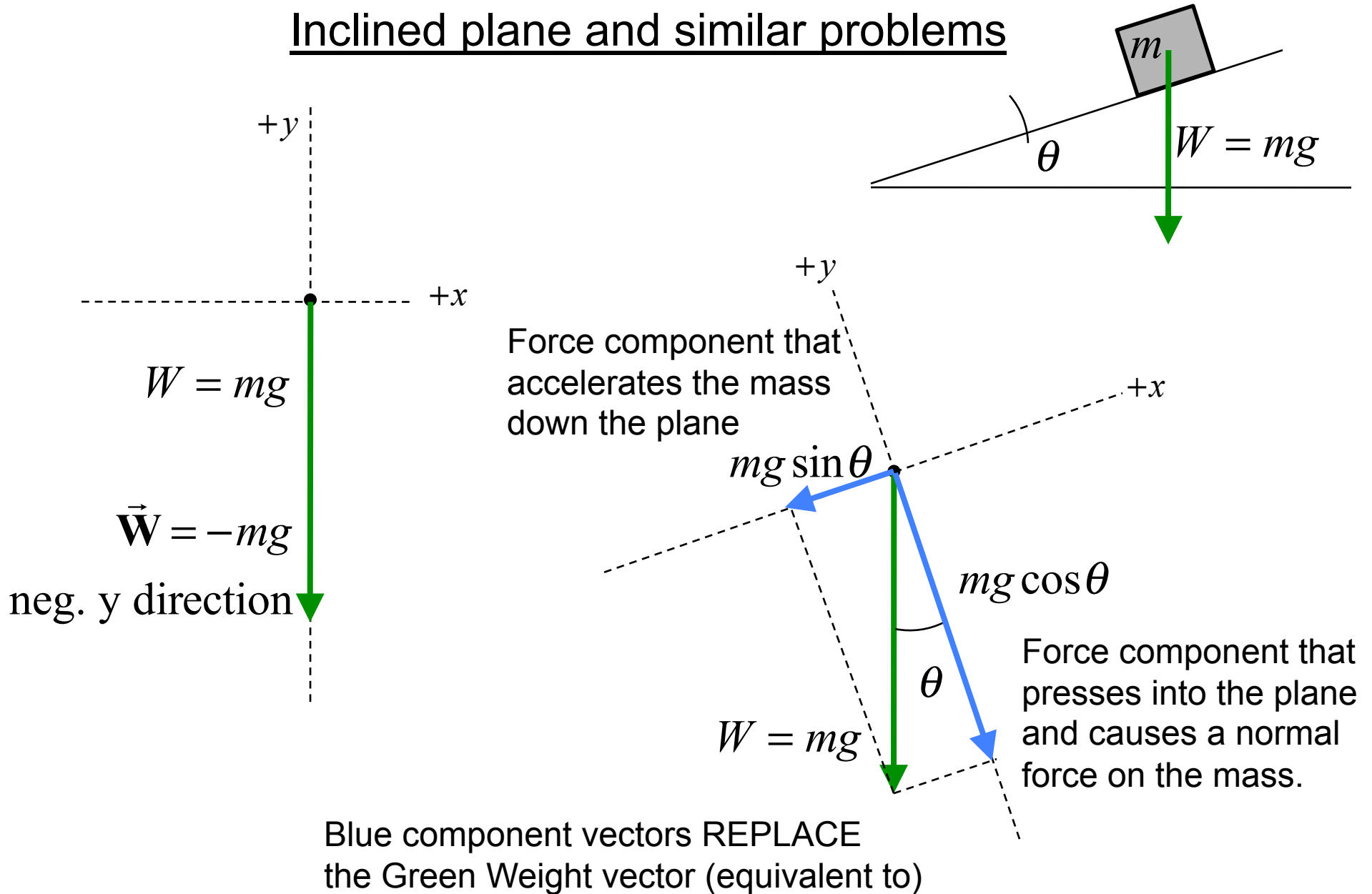
#### 4.11 *Equilibrium Application of Newton's Laws of Motion*

## Reasoning Strategy

- Select an object(s) to which the equations of equilibrium are to be applied.
- Draw a free-body diagram for each object chosen above. Include only forces acting on the object, not forces the object exerts on its environment.
- Choose a set of  $x$ ,  $y$  axes for each object and resolve all forces in the free-body diagram into components that point along these axes.
- Apply the equations and solve for the unknown quantities.

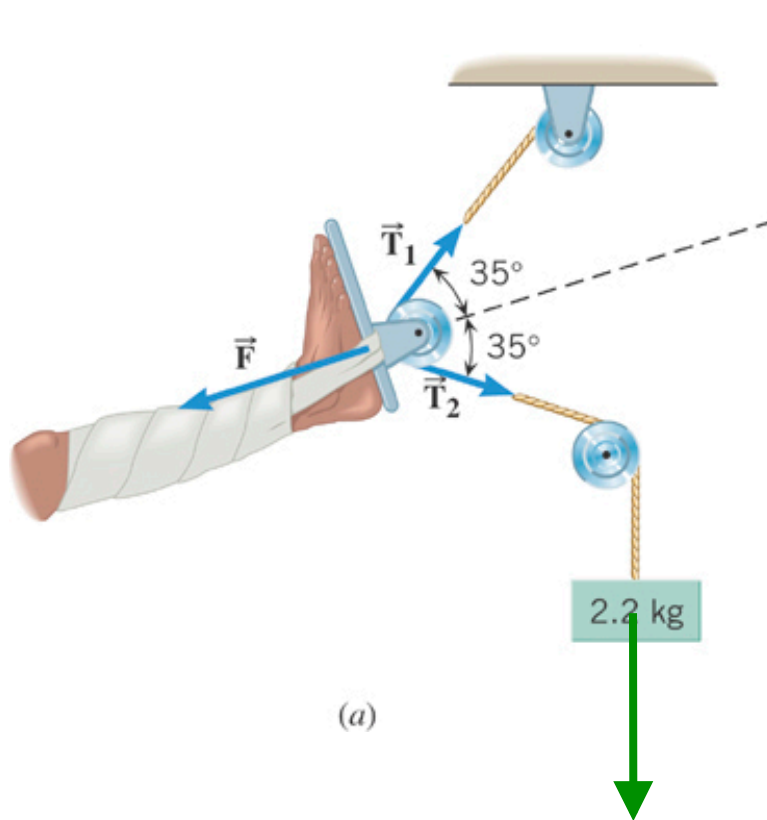
## 4.11 Equilibrium Application of Newton's Laws of Motion

### Inclined plane and similar problems

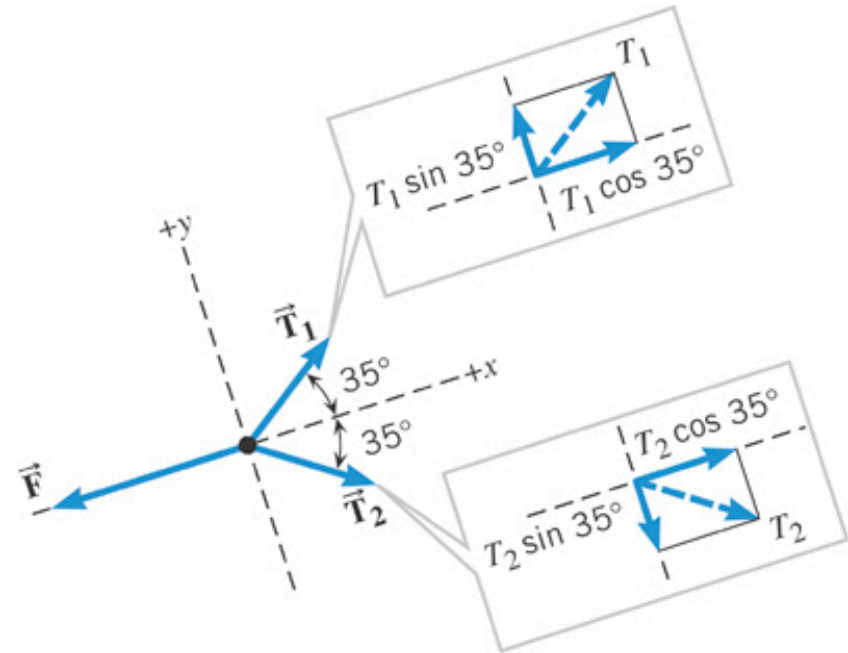




## 4.11 Equilibrium Application of Newton's Laws of Motion



(a)



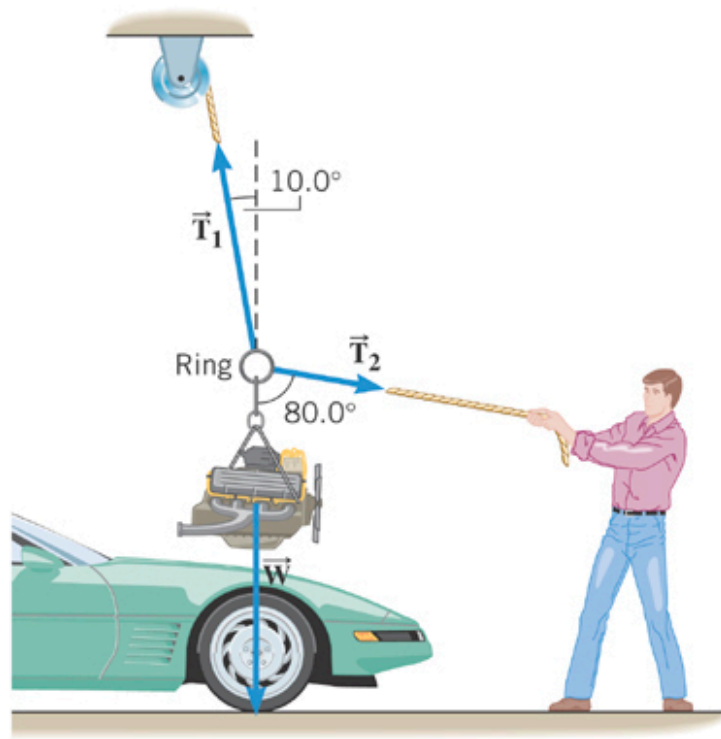
(b) Free-body diagram for the foot pulley

- 1)  $T = W = mg$
- 2) Net force vector = 0
- 3) Use  $x$  direction along leg
- 4)  $y$  is perpendicular to  $x$

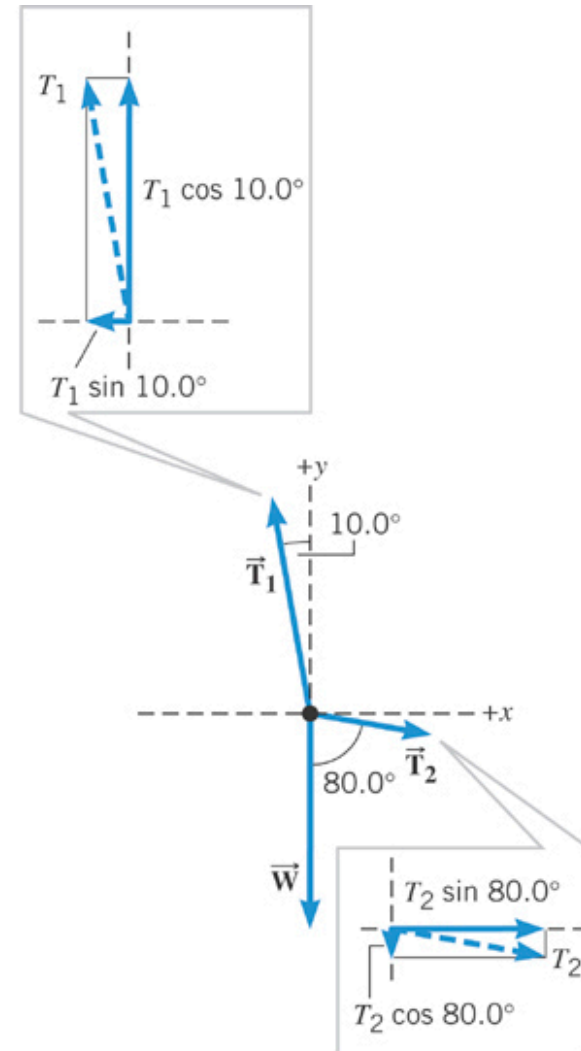
$$T_1 = T_2 = T \text{ (rope and pulleys insure this)}$$

$$x: +T_1 \cos 35^\circ + T_2 \cos 35^\circ - F = 0$$

## 4.11 Equilibrium Application of Newton's Laws of Motion



(a)



(b) Free-body diagram for the ring

#### 4.11 *Equilibrium Application of Newton's Laws of Motion*

Force	<i>x component</i>	<i>y component</i>
$\vec{T}_1$	$-T_1 \sin 10.0^\circ$	$+T_1 \cos 10.0^\circ$
$\vec{T}_2$	$+T_2 \sin 80.0^\circ$	$-T_2 \cos 80.0^\circ$
$\vec{W}$	0	$-W$

$$W = 3150 \text{ N}$$

#### 4.11 *Equilibrium Application of Newton's Laws of Motion*

$$\sum F_x = -T_1 \sin 10.0^\circ + T_2 \sin 80.0^\circ = 0$$

$$\sum F_y = +T_1 \cos 10.0^\circ - T_2 \cos 80.0^\circ - W = 0$$

The first equation gives  $T_1 = \left( \frac{\sin 80.0^\circ}{\sin 10.0^\circ} \right) T_2$

Substitution into the second gives

$$\left( \frac{\sin 80.0^\circ}{\sin 10.0^\circ} \right) T_2 \cos 10.0^\circ - T_2 \cos 80.0^\circ - W = 0$$

#### 4.11 *Equilibrium Application of Newton's Laws of Motion*

$$T_2 = \frac{W}{\left( \frac{\sin 80.0^\circ}{\sin 10.0^\circ} \right) \cos 10.0^\circ - \cos 80.0^\circ}$$

$$T_2 = 582 \text{ N}$$

$$T_1 = 3.30 \times 10^3 \text{ N}$$

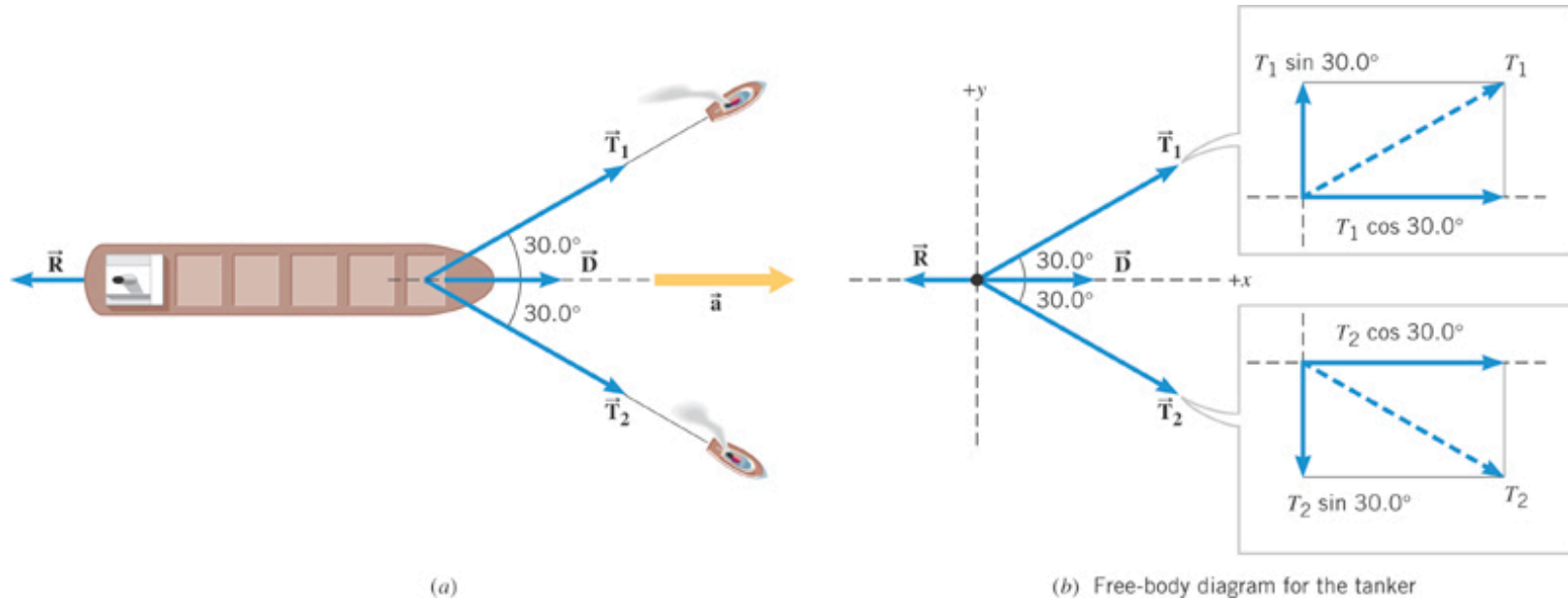
#### 4.12 *Nonequilibrium Application of Newton's Laws of Motion*

When an object is accelerating, it is not in equilibrium.

$$\sum F_x = ma_x$$

$$\sum F_y = ma_y$$

## 4.12 Nonequilibrium Application of Newton's Laws of Motion



The acceleration is along the  $x$  axis so  $a_y = 0$

#### 4.12 Nonequilibrium Application of Newton's Laws of Motion

Force	x component	y component
$\vec{T}_1$	$+T_1 \cos 30.0^\circ$	$+T_1 \sin 30.0^\circ$
$\vec{T}_2$	$+T_2 \cos 30.0^\circ$	$-T_2 \sin 30.0^\circ$
$\vec{D}$	$+D$	0
$\vec{R}$	$-R$	0



#### 4.12 *Nonequilibrium Application of Newton's Laws of Motion*

$$\sum F_y = +T_1 \sin 30.0^\circ - T_2 \sin 30.0 = 0$$

$$\Rightarrow T_1 = T_2$$

$$\begin{aligned}\sum F_x &= +T_1 \cos 30.0^\circ + T_2 \cos 30.0 + D - R \\ &= ma_x\end{aligned}$$

#### 4.12 *Nonequilibrium Application of Newton's Laws of Motion*

$$T_1 = T_2 = T$$

$$T = \frac{ma_x + R - D}{2 \cos 30.0^\circ} = 1.53 \times 10^5 \text{ N}$$