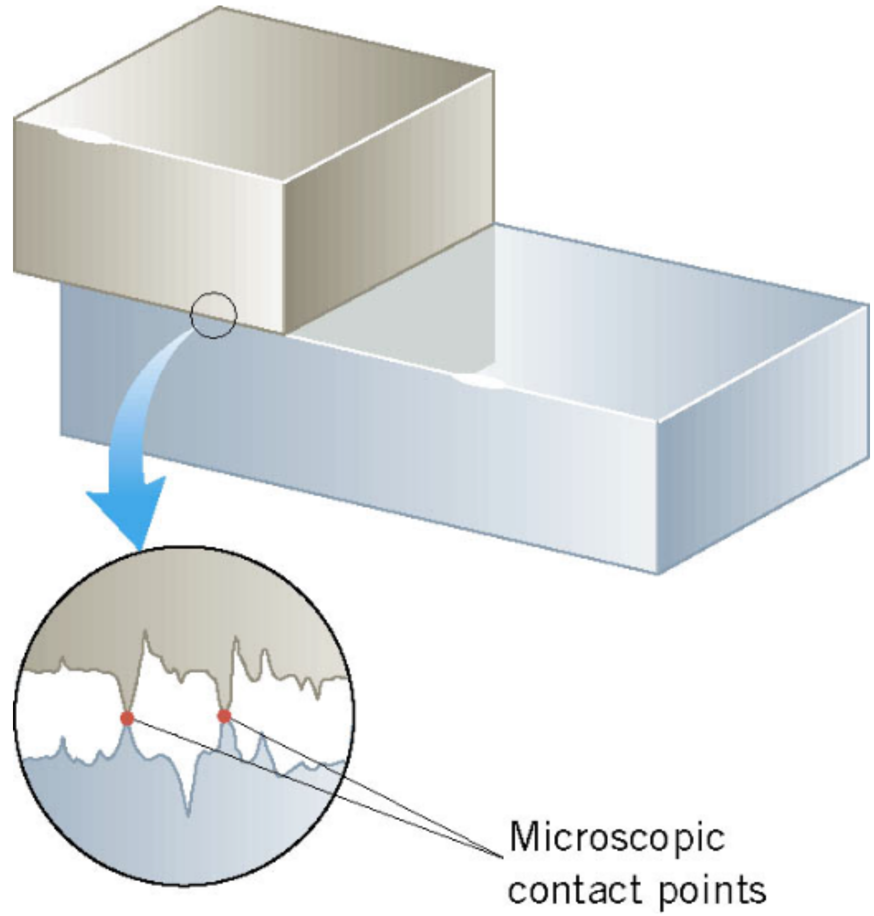
Chapter 4

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

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

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

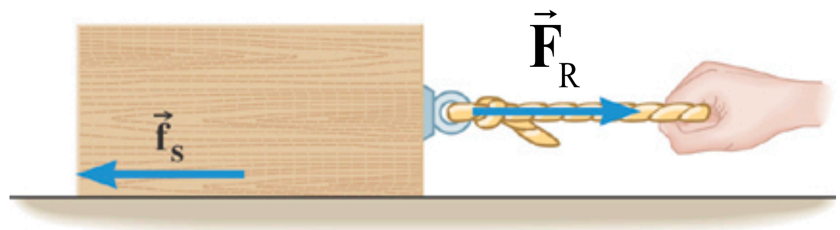
No movement
(*a*)

Block is at rest. Net force action on block

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

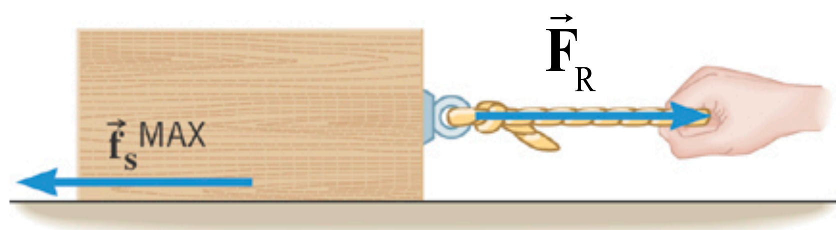
$$+F_R + (-f_S) = 0 \text{ (directions are opposite)}$$

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



No movement
(*b*)

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

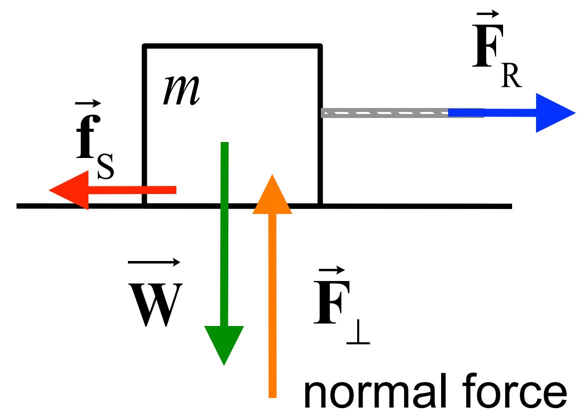


When movement just begins
(*c*)

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

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^{Max}



Friction equations are
for MAGNITUDES only.

$$f_S \le f_S^{\text{Max}} \quad \text{(object remains at rest)}$$

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

$$0 < \mu_S < 1$$

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

μ_S , coefficient of static friction.

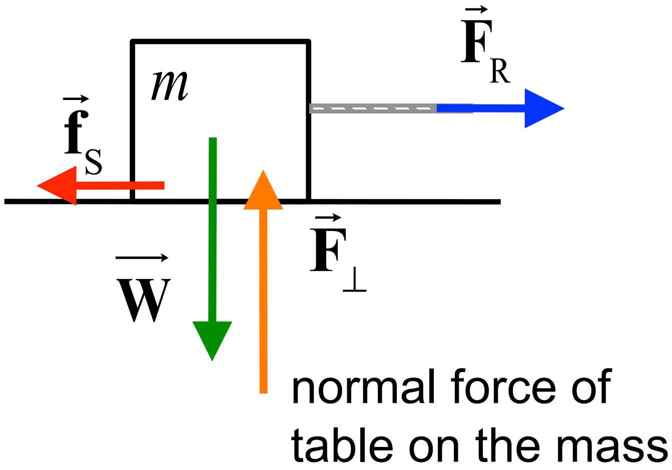
Example: It takes a horizontal force of at least 10,000 N to begin to move a 5,000 kg mass on flat road. What is the coefficient of friction between the two surfaces?

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

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

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

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



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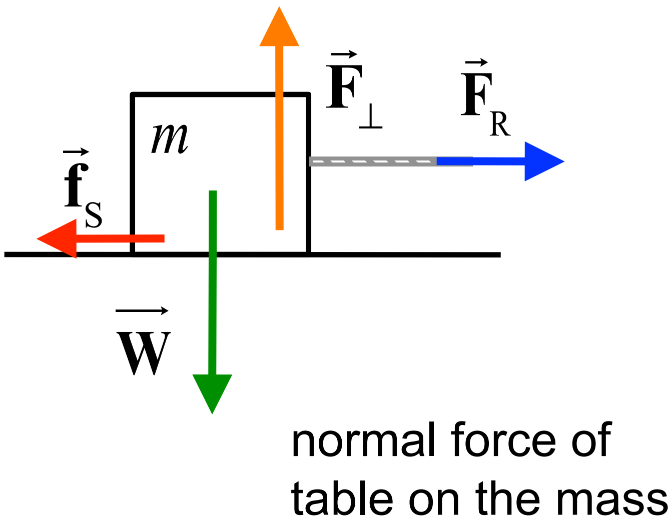
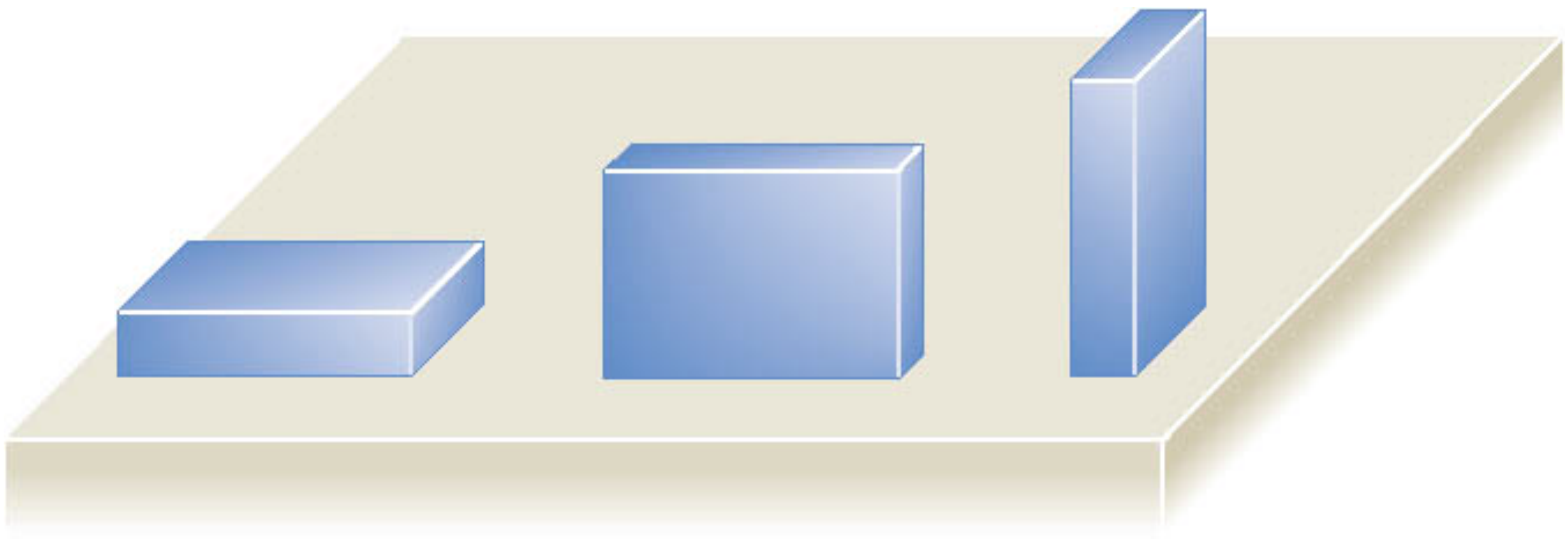


Note that the magnitude of the frictional force does not depend on the contact area of the surfaces.



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

$$f_{\mathrm{k}} = \mu_{\mathrm{k}} F_{\perp}$$

Friction equations are for MAGNITUDES only.

$$0 < \mu_{\mathrm{k}} < 1$$

is called the coefficient of kinetic friction.

$\vec{\mathbf{f}}_{\mathrm{k}}$ is a horizontal force.

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

OK because friction equations are for MAGNITUDES only.

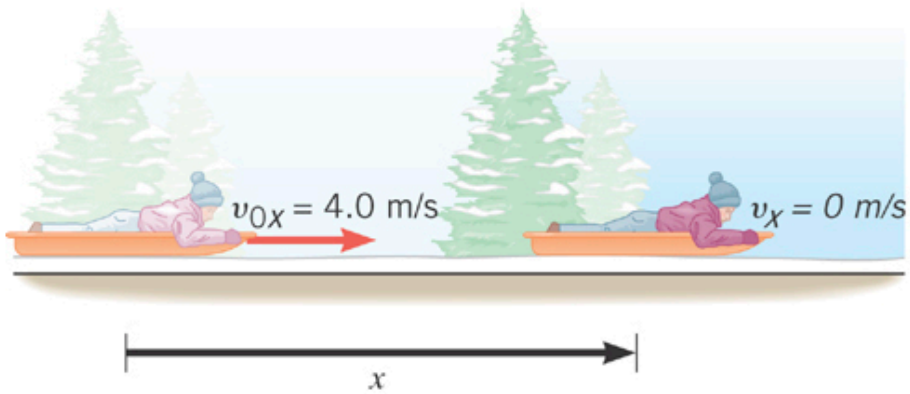
4.9 Static and Kinetic Frictional Forces

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

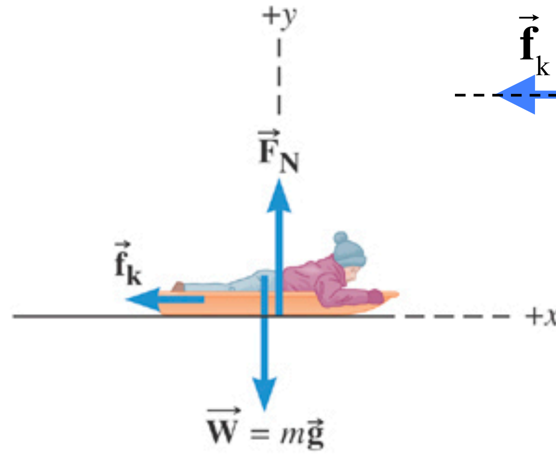
Materials	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Glass on glass (dry)	0.94	0.4
Ice on ice (clean, 0 °C)	0.1	0.02
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on ice	0.1	0.05
Steel on steel (dry hard steel)	0.78	0.42
Teflon on Teflon	0.04	0.04
Wood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

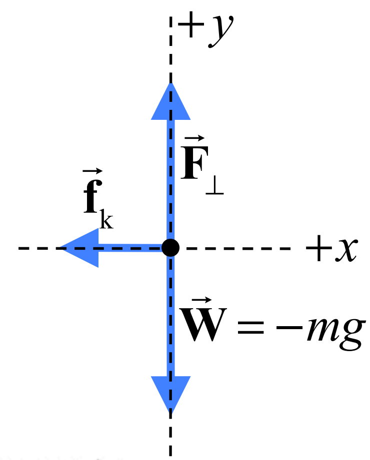
*The last column gives the coefficients of kinetic friction, a concept that will be discussed shortly.

4.9 Static and Kinetic Frictional Forces



(a)

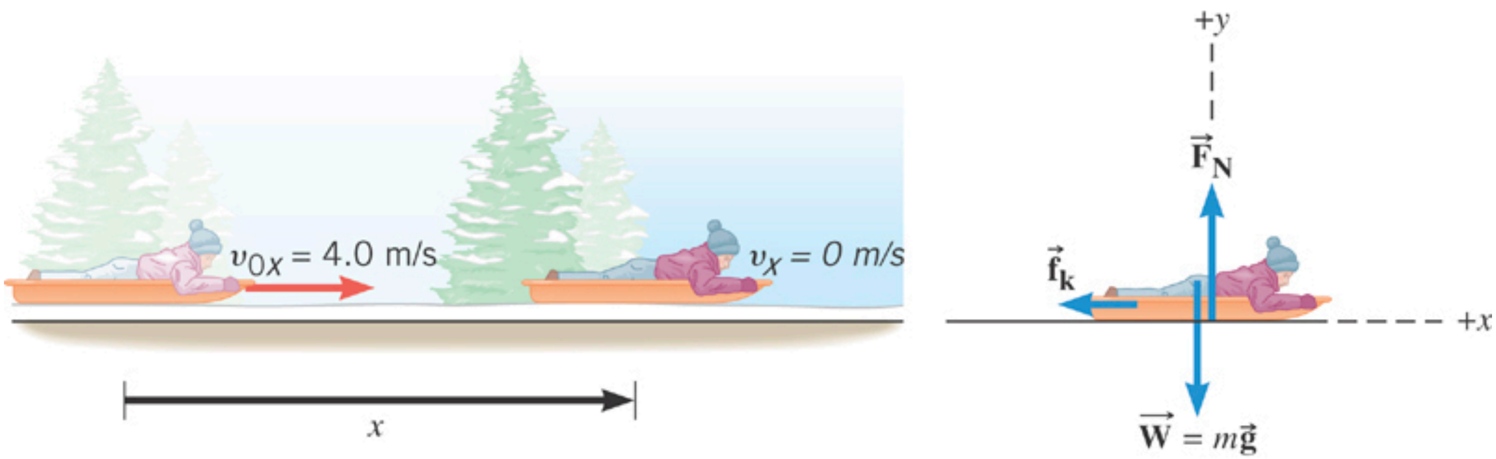




Showing just the forces acting on one object is called a “Free Body Diagram”

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?

$$f_k = \mu_k F_N$$

<u>Friction equations are for MAGNITUDES only.</u>

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

4.10 The Tension Force

<u>Cables and ropes transmit forces through ***tension***.</u>

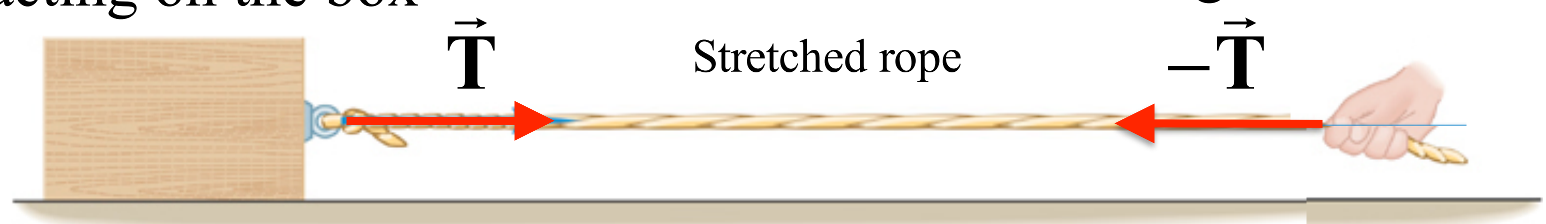
Box surface force acting on the rope

Hand force acting on the rope

(*b*)

Rope tension force acting on the box

Rope tension force acting on the hand

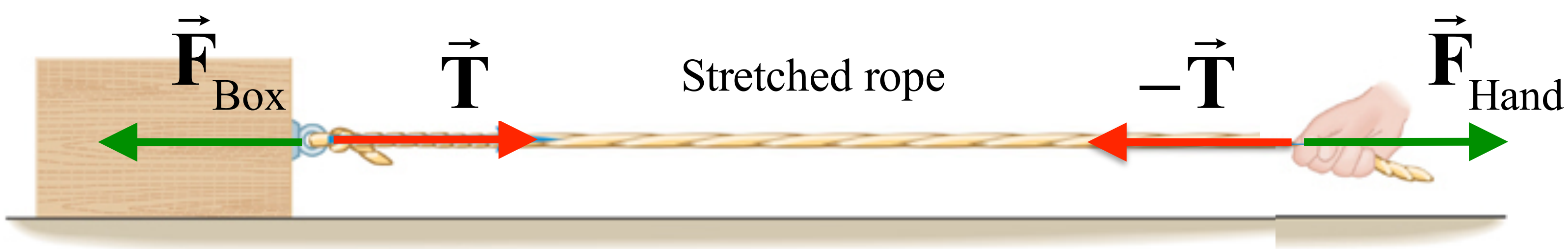


$\left(\vec{\mathbf{F}}_{\text{Box}}, \vec{\mathbf{T}}\right)$ These are Newton's 3rd law Action – Reaction pairs $\left(-\vec{\mathbf{T}}, \vec{\mathbf{F}}_{\text{Hand}}\right)$

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

4.10 The Tension Force

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



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

These are Newton's 3rd law
Action – Reaction pairs

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

Tension pulls on box

Box pulls on rope

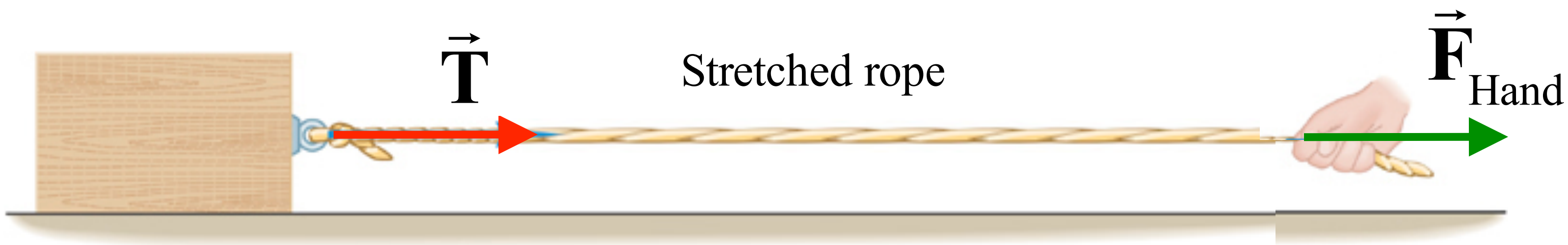
Tension pulls on hand

Hand pulls on rope

4.10 The Tension Force

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

These are the important forces



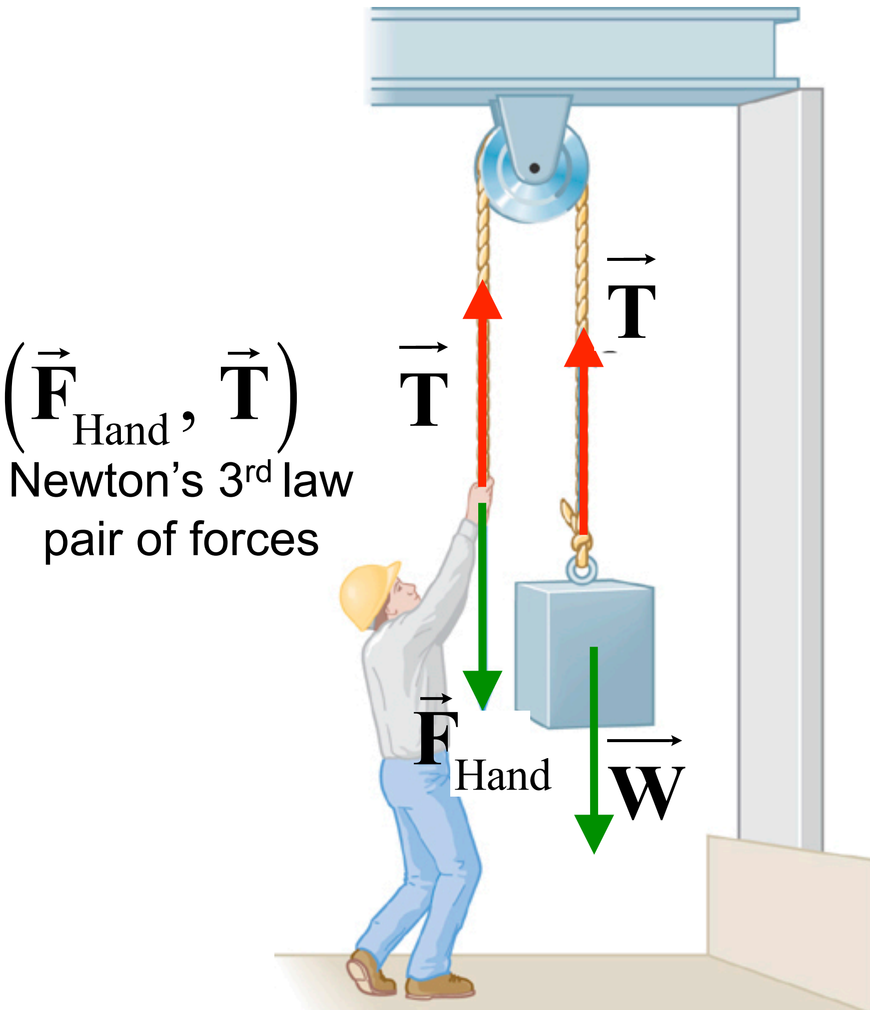
Hand force causes a tension force on the box

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!

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

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

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

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.

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

Reasoning Strategy

• Select an object(s) to which the equations of equilibrium are to be applied.

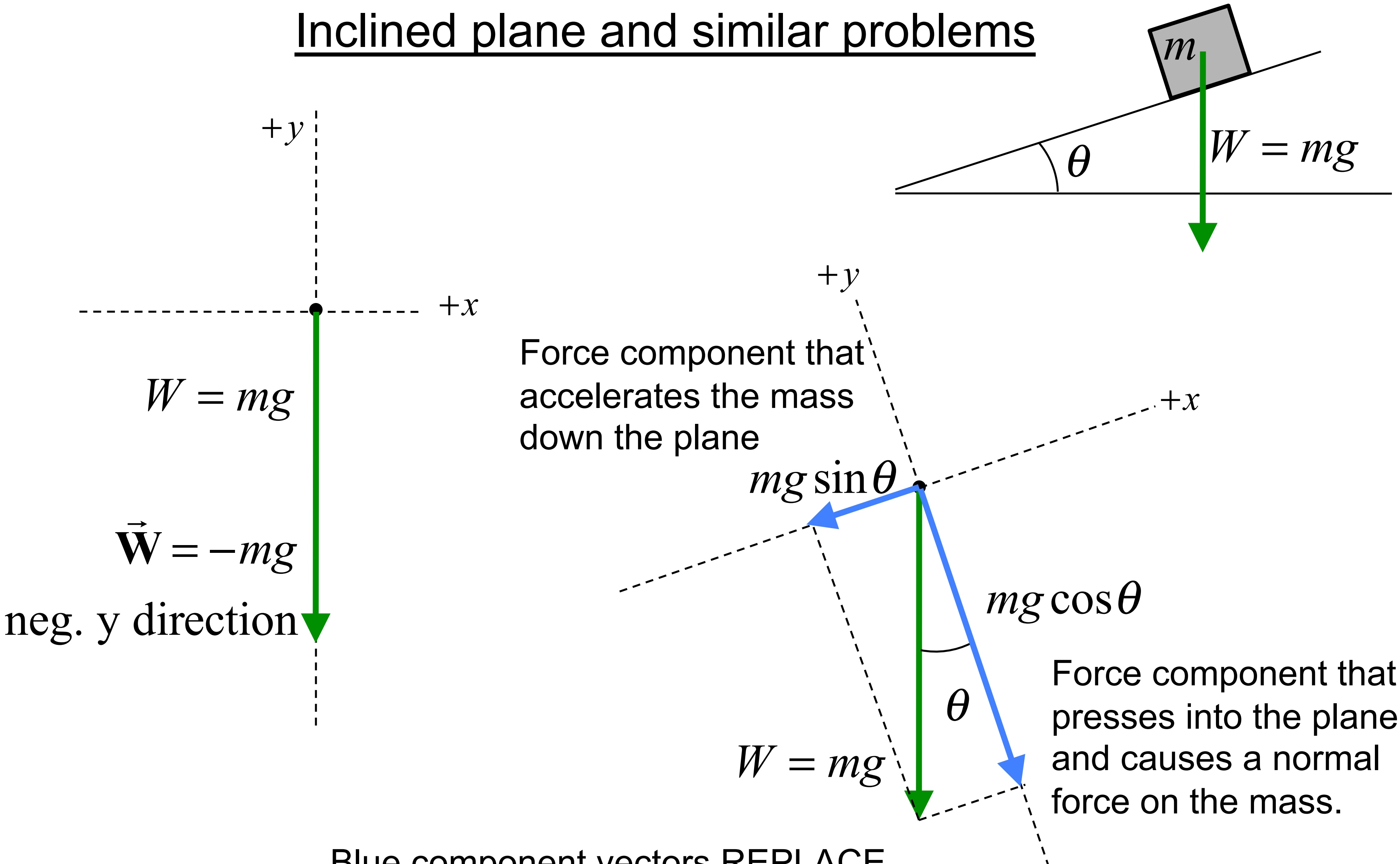
• Draw a free-body diagram for each object chosen above. Include only forces acting on the object, not forces the object exerts on its environment.

• 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.

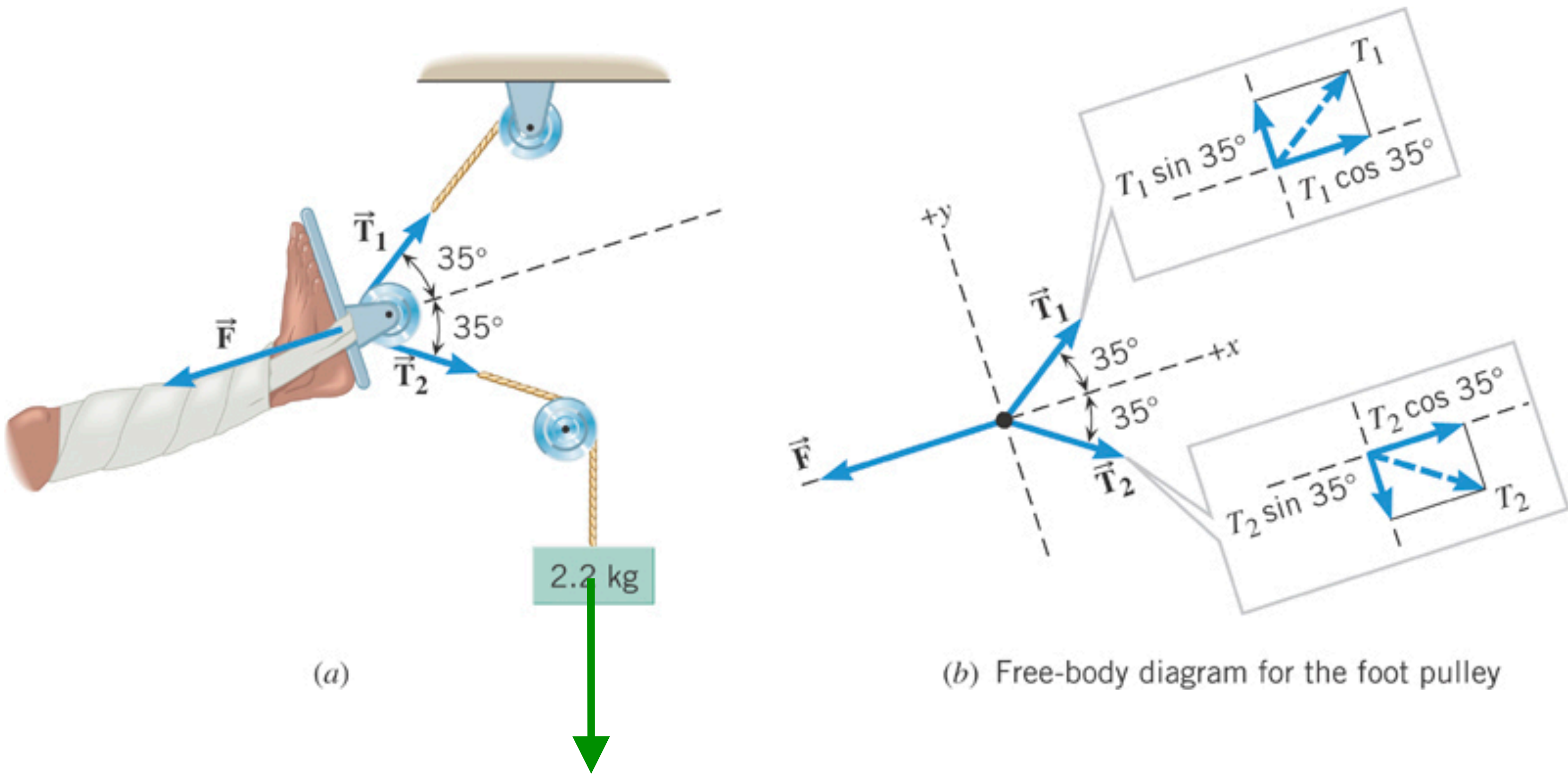
4.11 Equilibrium Application of Newton's Laws of Motion

Inclined plane and similar problems



Blue component vectors REPLACE the Green Weight vector (equivalent to)

4.11 Equilibrium Application of Newton's Laws of Motion



1) $T = W = mg$

2) Net force vector $= 0$

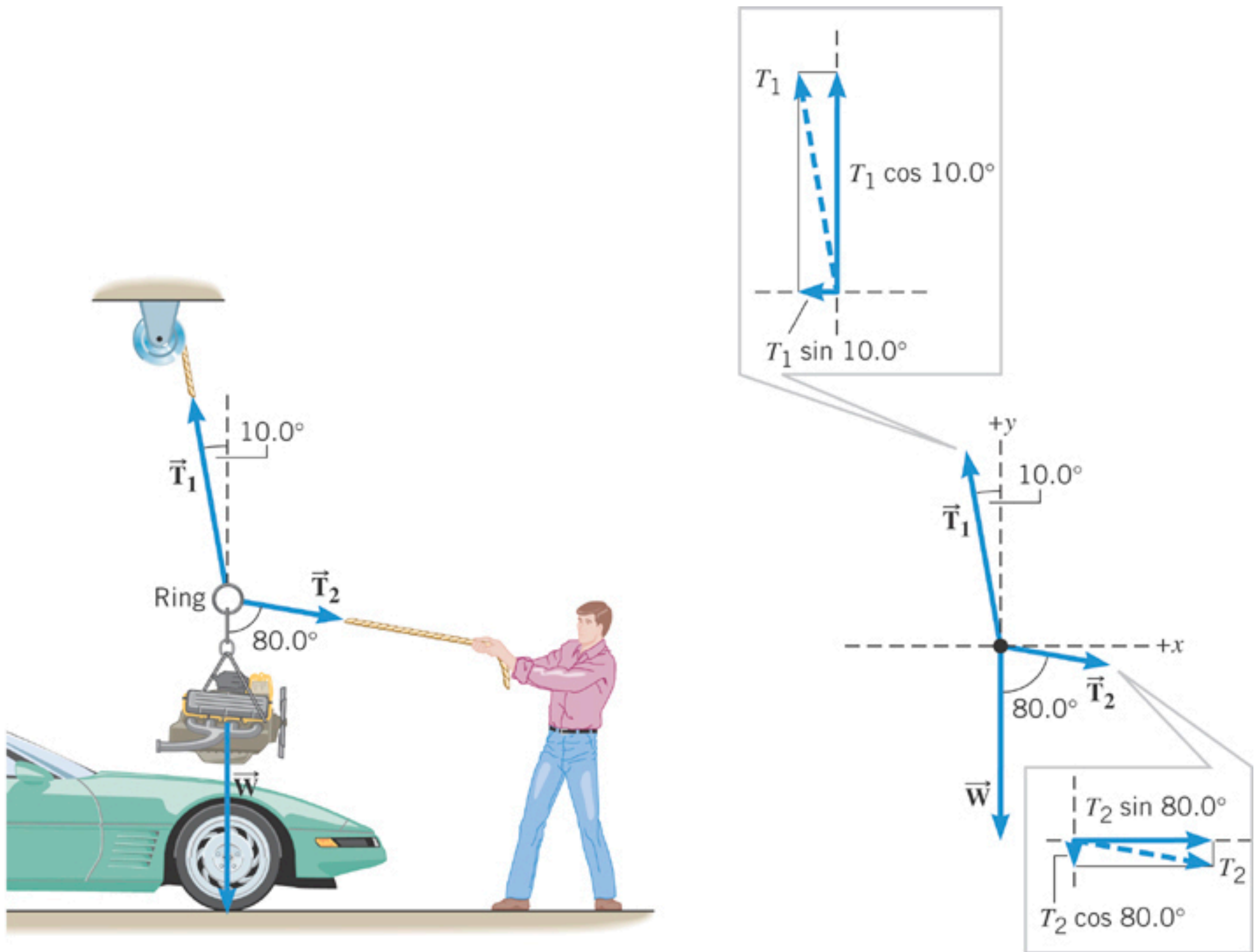
3) Use x direction along leg

4) y is perpendicular to x

$T_1 = T_2 = T$ (rope and pulleys insure this)

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

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	*x component*	*y* component
$\vec{\mathbf{T}}_1$	$-T_1 \sin 10.0^\circ$	$+T_1 \cos 10.0^\circ$
$\vec{\mathbf{T}}_2$	$+T_2 \sin 80.0^\circ$	$-T_2 \cos 80.0^\circ$
$\vec{\mathbf{W}}$	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 $T_1 = \left(\dfrac{\sin 80.0^\circ}{\sin 10.0^\circ}\right) T_2$

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

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

$$T_2 = 582\ \text{N} \qquad T_1 = 3.30 \times 10^3\ \text{N}$$

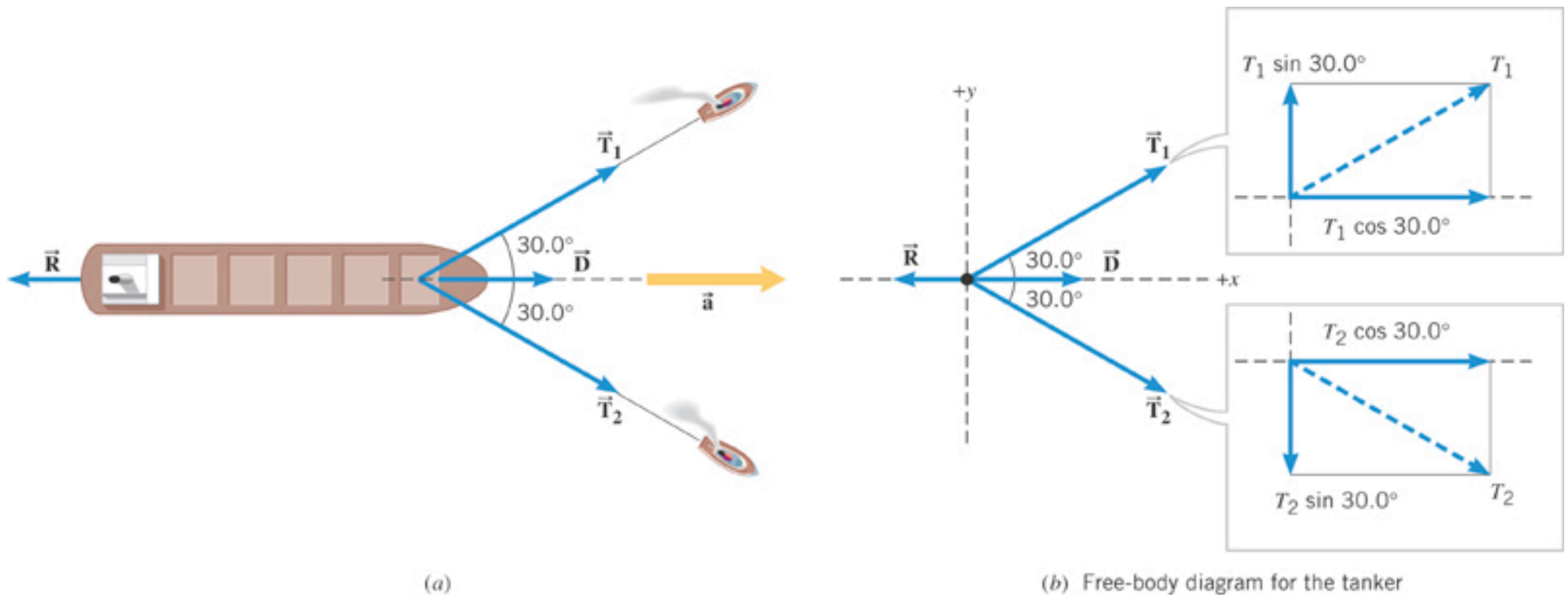
4.12 Nonequilibrium Application of Newton's Laws of Motion

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



(b) Free-body diagram for the tanker

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

4.12 Nonequilibrium Application of Newton's Laws of Motion

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

$$\Rightarrow T_1 = T_2$$

$$\sum F_x = +T_1 \cos 30.0^\circ + T_2 \cos 30.0 + D - R$$

$$= ma_x$$

4.12 Nonequilibrium Application of Newton's Laws of Motion

$$T_1 = T_2 = T$$

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