Chapter 4

Forces and Newton's Laws of Motion

continued

Quiz 3

Newton’s Law of Universal Gravitation

Every particle in the universe exerts an attractive force on every other particle.

A particle is a piece of matter, small enough in size to be regarded as a mathematical point.

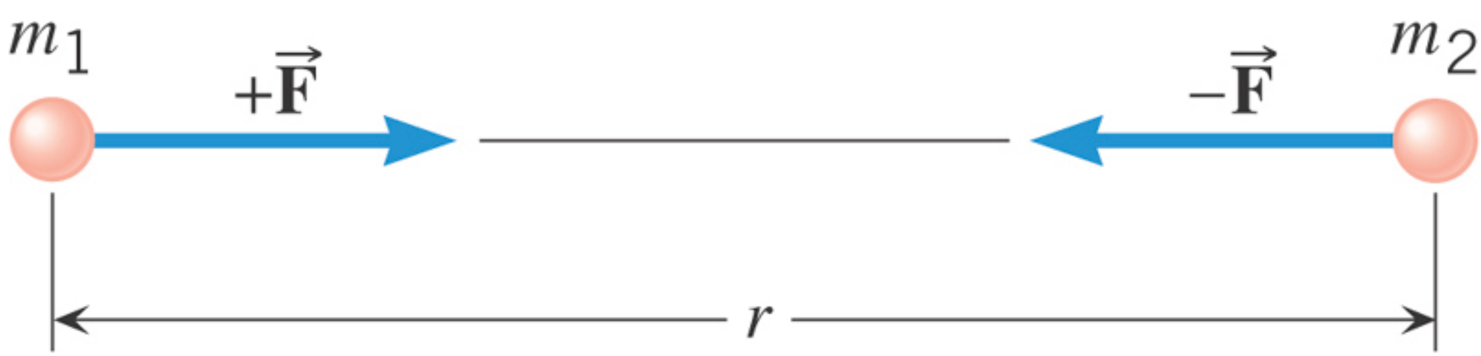
The force that each exerts on the other is directed along the line joining the particles.

4.7 The Gravitational Force

For two particles that have masses m_1 and m_2 and are separated by a distance r, the force has a magnitude given by

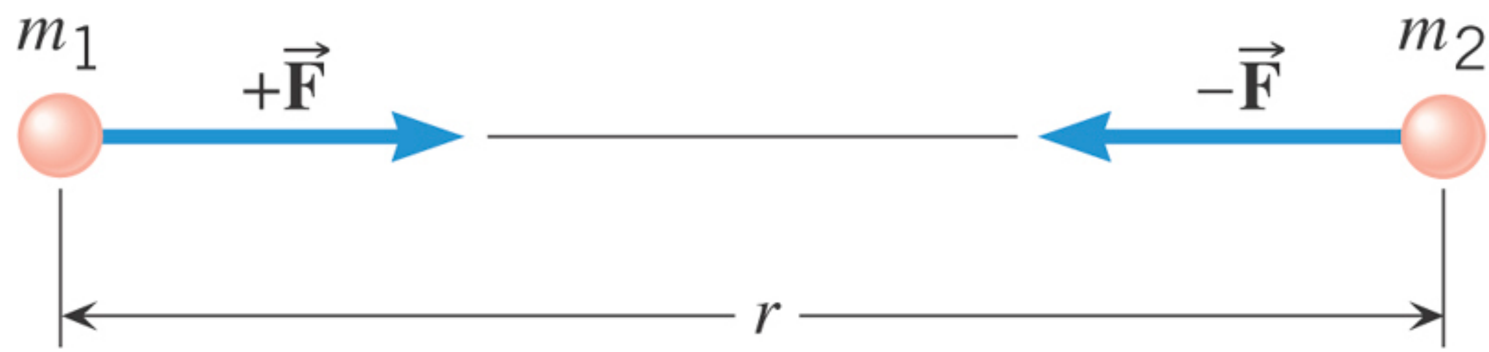
$$F = G\frac{m_1 m_2}{r^2}$$

$$G = 6.673\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}$$



the same magnitude of force acts on each mass, no matter what the values of the masses.

4.7 The Gravitational Force

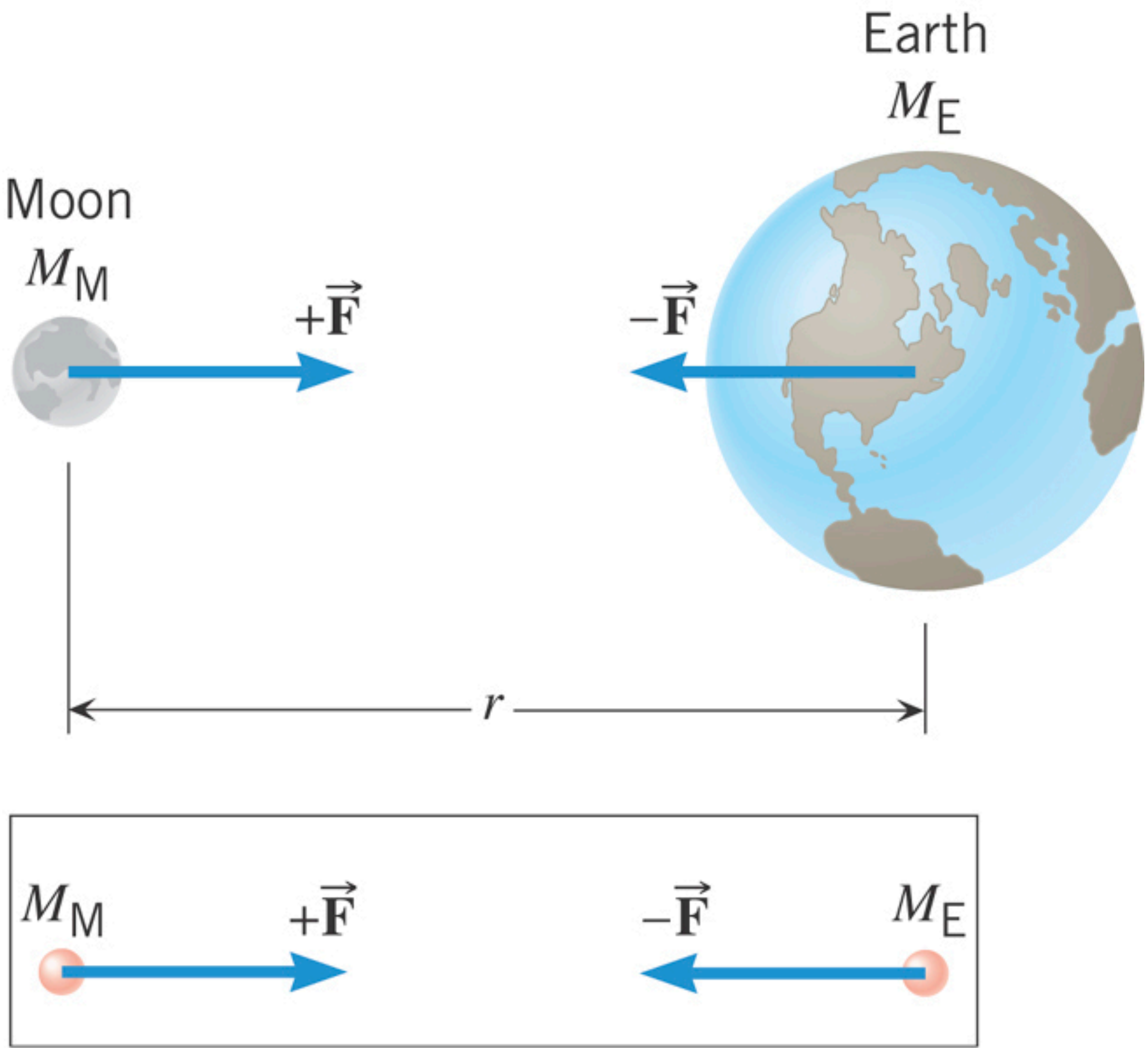


$$F = G\frac{m_1 m_2}{r^2}$$

$$= \left(6.67\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}\right)\frac{(12\ \mathrm{kg})(25\ \mathrm{kg})}{(1.2\ \mathrm{m})^2}$$

$$= 1.4\times10^{-8}\ \mathrm{N}$$

4.7 The Gravitational Force



Definition of Weight

The weight of an object on or above the earth is the gravitational force that the earth exerts on the object. The weight always acts downwards, toward the center of the earth.

On or above another astronomical body, the weight is the gravitational force exerted on the object by that body.

SI Unit of Weight: newton (N)

4.7 The Gravitational Force

Relation Between Mass and Weight

<u>WEIGHT is a force vector</u>

$$\vec{\mathbf{W}} = G\frac{mM_E}{r^2}, \text{ downward}$$

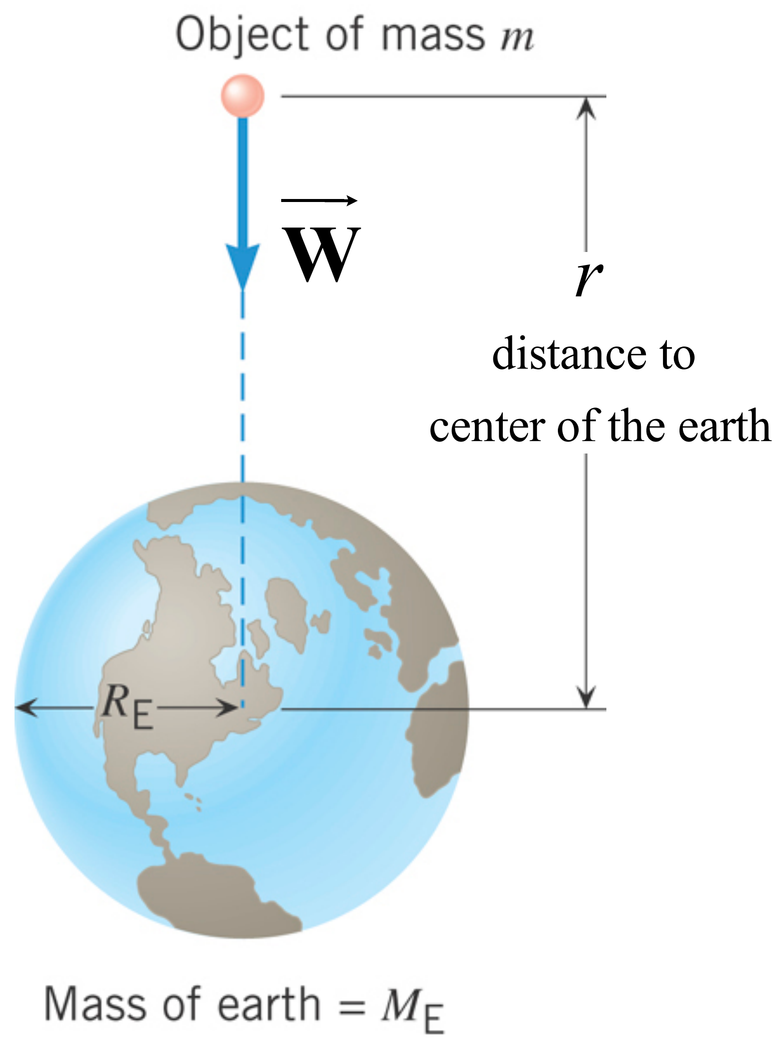
<u>WEIGHT(magnitude) of mass m</u>

$$W = mg, \qquad g = G\frac{M_E}{r^2}$$

<u>Your WEIGHT</u>

WEIGHT DEFINITION

Your "weight" is the force that <u>gravity</u> applies on your body.



Near the earth's surface

$$\boxed{r = R_{\mathrm{E}} = 6.38\times10^{6}\ \mathrm{m}}$$

Radius of the earth

$$g = G\frac{M_{\mathrm{E}}}{R_{\mathrm{E}}^{2}}$$

$$= \left(6.67\times10^{-11}\,\mathrm{N\cdot m^2/kg^2}\right)\frac{\left(5.98\times10^{24}\ \mathrm{kg}\right)}{\left(6.38\times10^{6}\ \mathrm{m}\right)^{2}}$$

$$= 9.80\ \mathrm{m/s^2}$$

This is why acceleration due to gravity is this value on the earth.

Your WEIGHT on the earth

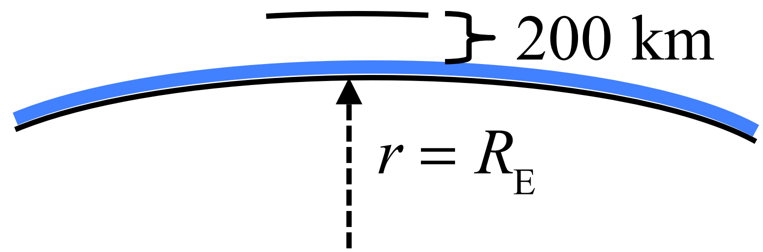
$$W = mg$$

for example: $m = 80.0\,\mathrm{kg}$,

$$W = mg = 784\,\mathrm{N}$$

Near the earth's surface

In orbit at altitude = 200 km



$$\boxed{g = 9.80\ \text{m/s}^2}$$

At radius of the earth

At 200 km above the earth

$$r' = R_E + 200\ \text{km} = \underline{6.38\times10^6} + 0.2\times10^6\ \text{m}$$

$$= \underline{6.58\times10^6\ \text{m}}$$

$$\boxed{g' = 9.20\ \text{m/s}^2}$$

$$g' = \frac{GM_E}{r'^2} = 9.20\ \text{m/s}^2$$

In low-earth orbit,
your weight is almost the same as on earth. NOT ZERO!

4.7 The Gravitational Force

Can you feel gravity (the gravitational force) ?

Most people would say yes!

Consider standing on the concrete floor.

Gravity pulls down on you and compresses your body. You feel most of the compression in your legs, because most of your body mass is above them.

Consider hanging by your hands from a 100 m high diving board.

Gravity pull down on you and stretches your body.You feel most stretching in your arms, because most body mass is below them.

Let go of the 100 m high diving board.

While gravity accelerates you downward, what do you feel ?

You don't feel stretched, and you don't feel compressed.
You feel "weightless", yes, but your weight is still $W = mg$.

4.7 The Gravitational Force

The ONLY thing a person can feel is a stretch or compression of your body parts, mostly at a point of contact. If your body is not stretched or compressed, you will feel like you are floating.

Gravity ALONE will not stretch or compress your body.

Hanging from the board, the board also pulls up on your arms. Newton's 3rd law!

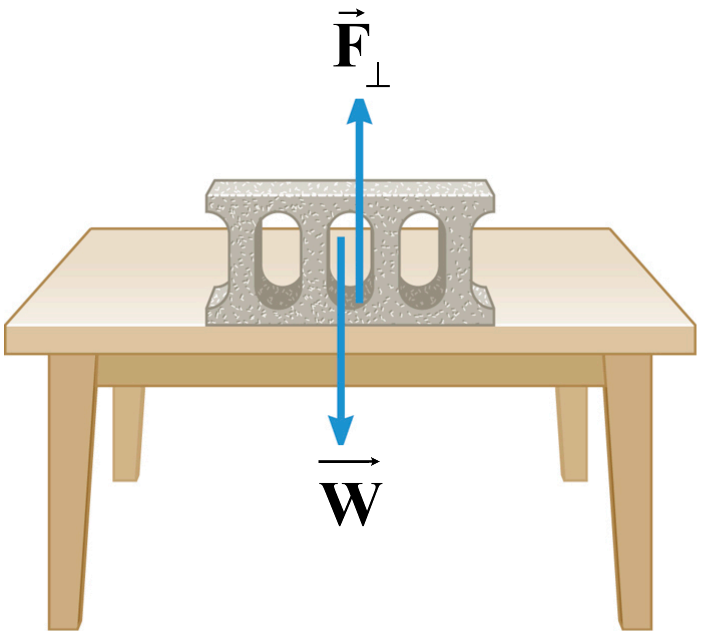
Standing on the ground, the ground also pushes up on the bottom of your feet. Newton's 3rd law!

While falling, the earth pulls on you and you pull on the earth. Gravity requires no contact. YOU CANNOT FEEL GRAVITY.

Definition of the Normal Force

The normal force is one component of the force that a surface exerts on an object with which it is in contact – namely, the component that is perpendicular to the surface.

$\vec{\mathbf{F}}_{\perp}$ sometimes written as $\vec{\mathbf{F}}_{N}$



4.8 The Normal Force

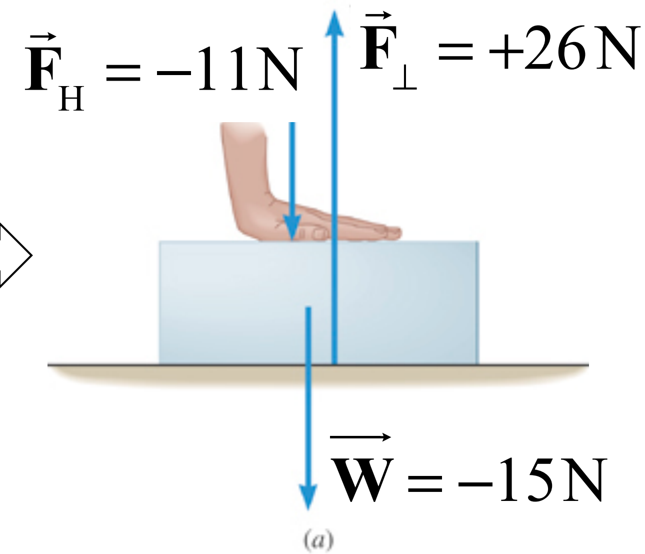
$\vec{\mathbf{F}}_{\perp}$: Normal (or perpendicular) force

$\vec{F}_{\perp}$ is the magnitude

$$\vec{\mathbf{F}}_{\text{Net}} = \vec{\mathbf{F}}_{\perp} + \overrightarrow{\mathbf{W}} + \vec{\mathbf{F}}_{\text{H}} = 0$$

$$= \mathbf{F}_{\perp} + \left(-11\ \text{N}\right) + \left(-15\ \text{N}\right)$$

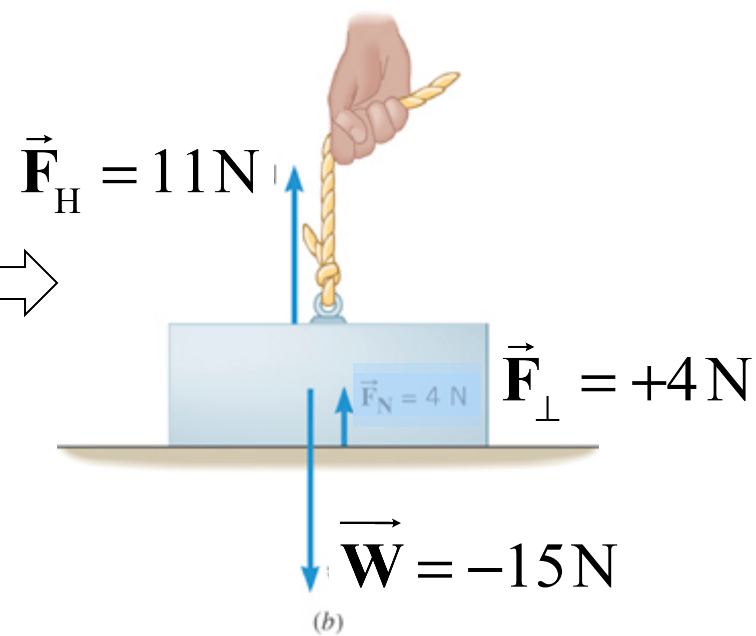
$$\mathbf{F}_{\perp} = +26\ \text{N}$$



$$\vec{\mathbf{F}}_{\text{Net}} = \vec{\mathbf{F}}_{\perp} + \vec{\mathbf{F}}_{H} + \overrightarrow{\mathbf{W}} = 0$$

$$= \vec{\mathbf{F}}_{\perp} + 11\ \text{N} + \left(-15\ \text{N}\right)$$

$$\vec{\mathbf{F}}_{\perp} = +4\ \text{N}$$



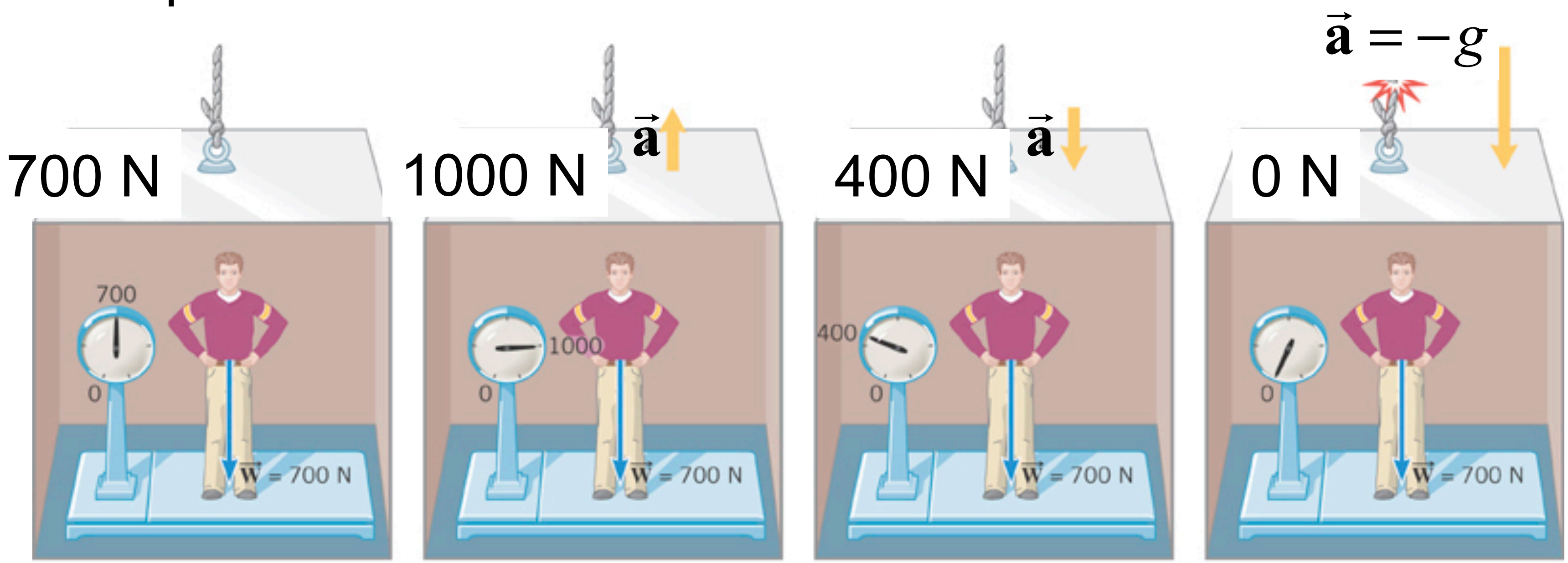
Apparent Weight = Normal force acting on an object

The apparent weight of an object is the reading of the scale.

It is equal to the normal force the scale exerts on the man.

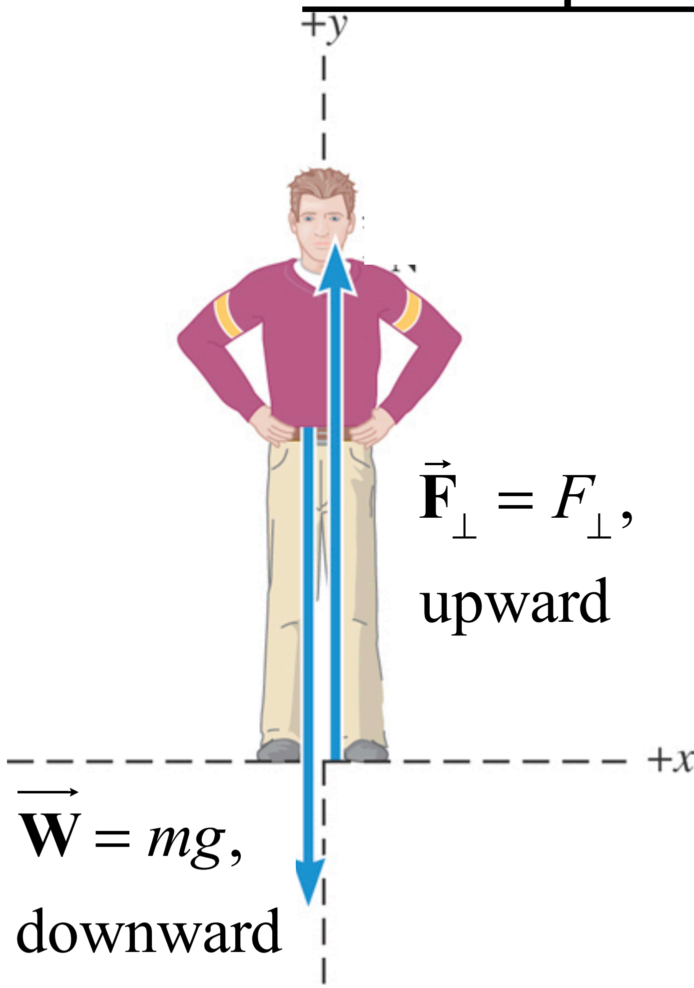
Also, by Newton's 3rd law

It is equal to the normal force the man exerts on the scale.



Acceleration	Acceleration	Acceleration	Free fall
$a = 0$, v constant	a, upward	a, downward	$a = g$, downward

For the person being accelerated (a)



$$\sum F_y = \vec{\mathbf{F}}_\perp + \overrightarrow{\mathbf{W}}; \quad \sum F_y = ma$$

$$\vec{\mathbf{F}}_\perp + \overrightarrow{\mathbf{W}} = ma$$

$$+F_\perp + \left(-mg\right) = ma$$

$$F_\perp = mg + ma$$

apparent weight

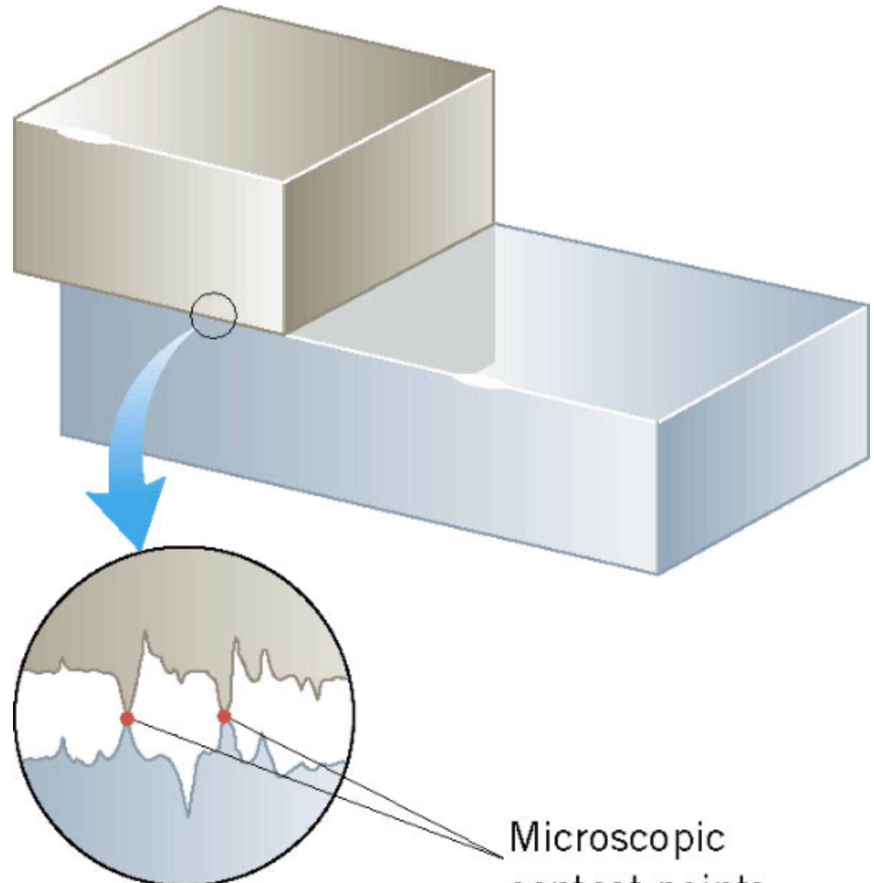
true weight

a upward: apparent weight > true weight

a downward: apparent weight < true weight

4.9 Static and Kinetic Frictional Forces

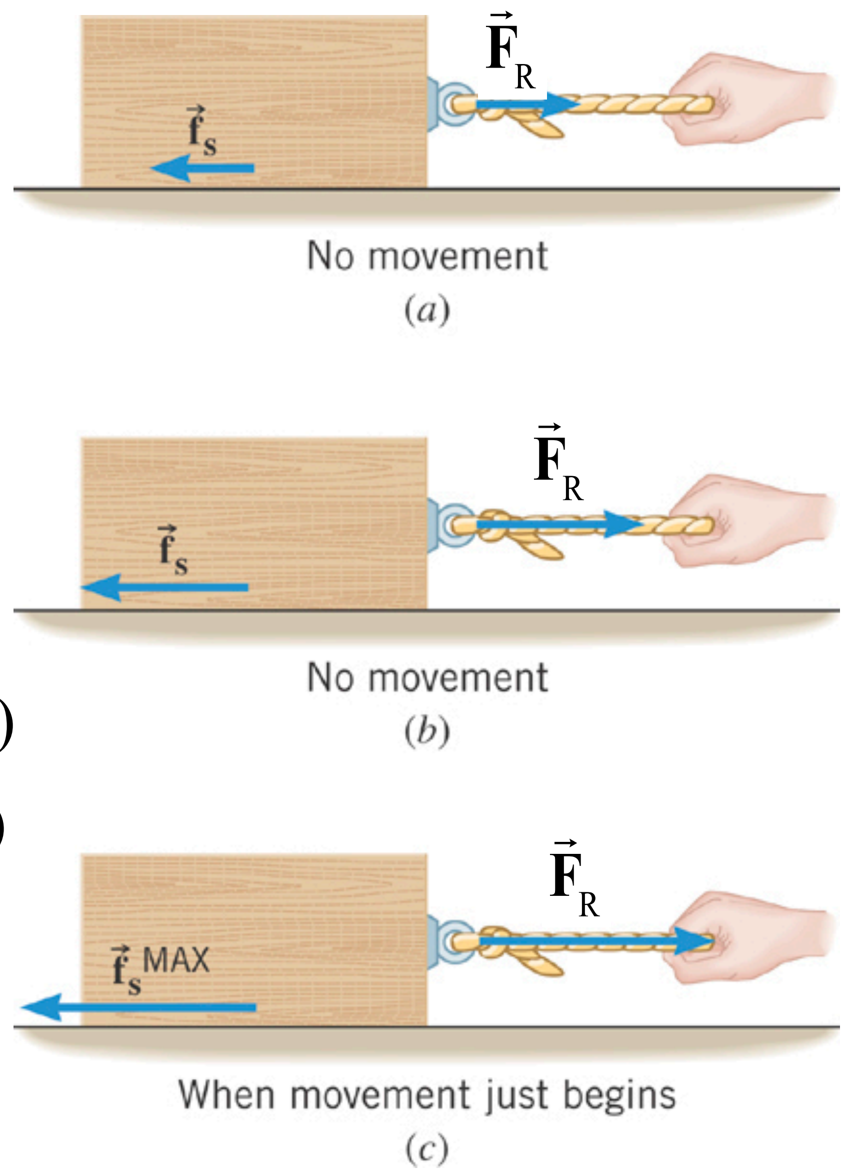
When an object is in contact with a surface forces can act on the objects. The component of this force acting on each object that is parallel to the surface is called the ***frictional force***.



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***.



Block is at rest. Net force action on block

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

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

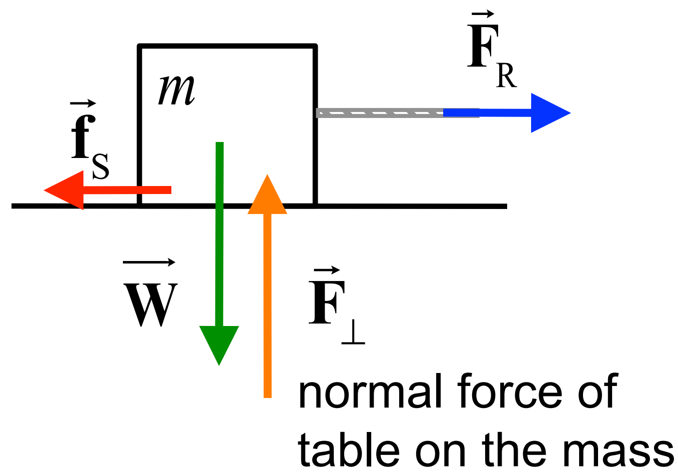
$$F_R = f_S \text{ (magnitudes the same)}$$

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^{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}



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

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

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

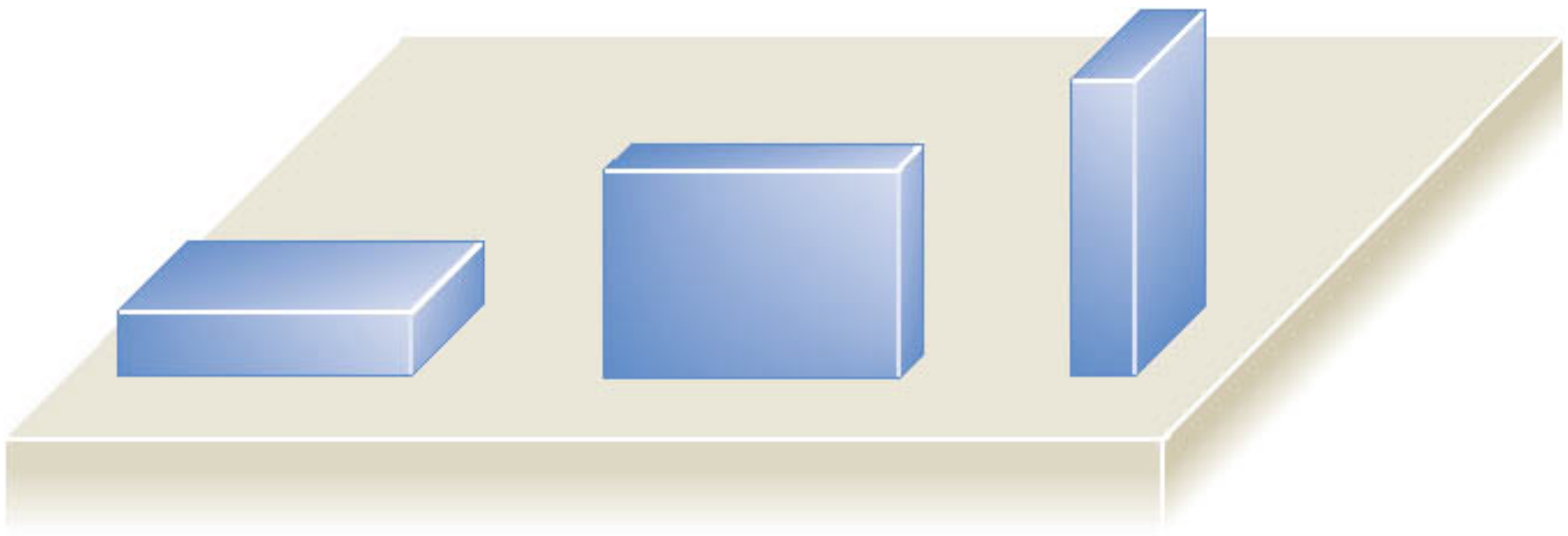
With no other vertical forces, $F_\perp = W = mg$

$$0 < \mu_S < 1$$

μ_S , coefficient of <u>static friction</u>.

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.

$$f_k = \mu_k F_N$$

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

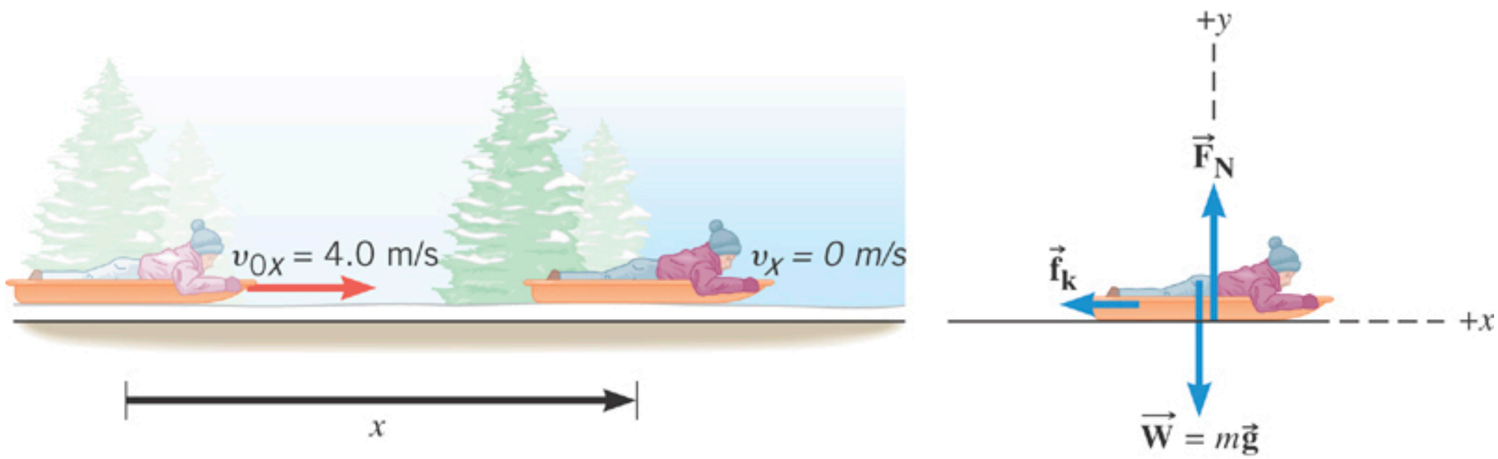
4.9 Static and Kinetic Frictional Forces

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

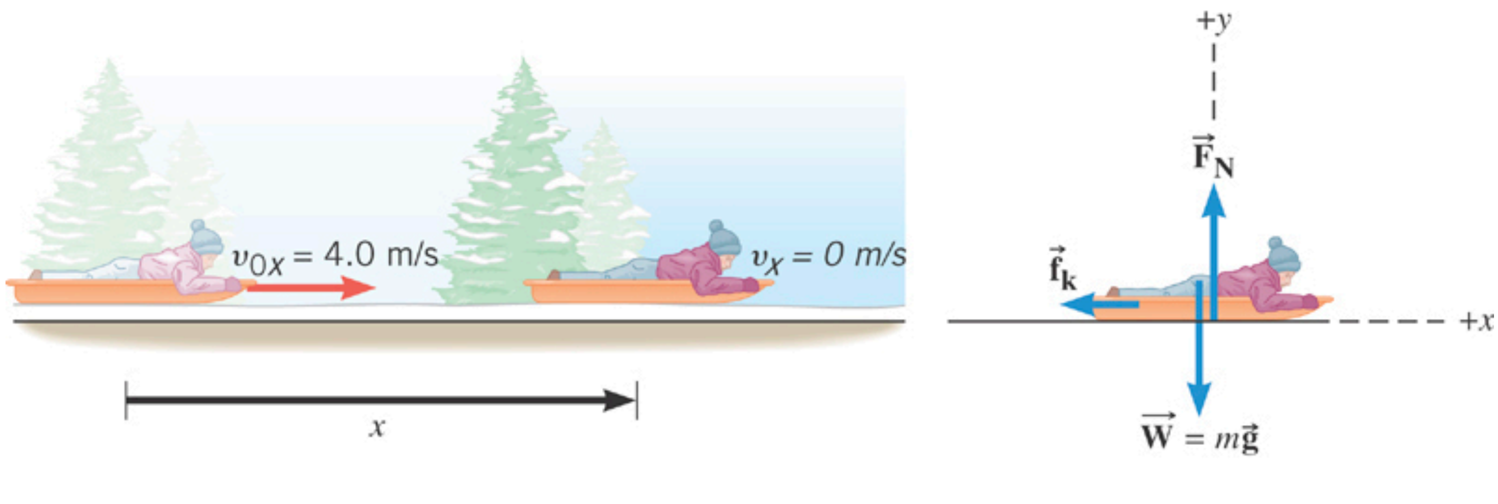


(a)

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

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

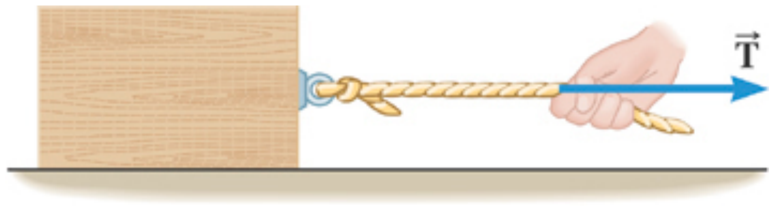
Suppose the coefficient of kinetic friction is 0.05 and the total mass is 40kg. What is the kinetic frictional force?

$$f_k = \mu_k F_N = \mu_k mg =$$

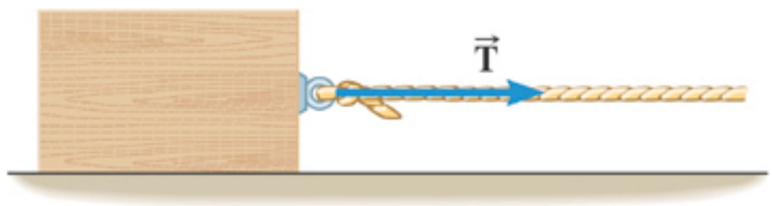
$$0.05(40\,\text{kg})(9.80\,\text{m/s}^2) = 20\,\text{kg}$$

4.10 The Tension Force

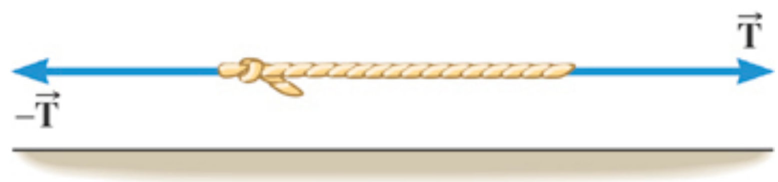
Cables and ropes transmit forces through ***tension***.



(a)

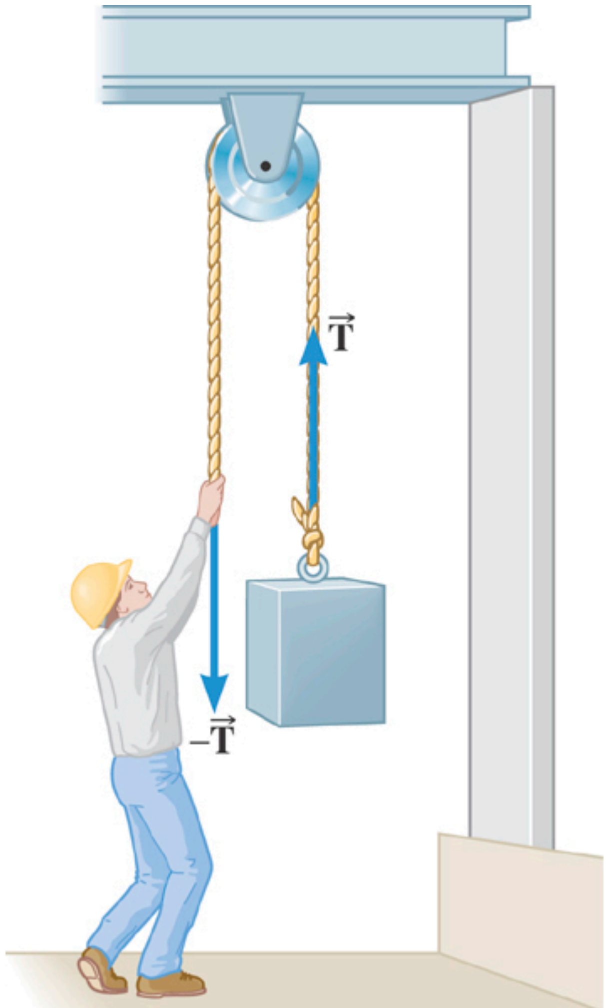


(b)



(c)

4.10 The Tension Force



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

If the rope passes around a massless, frictionless pulley, the tension will be transmitted to the other end of the rope undiminished.

Definition of Equilibrium

An object is in equilibrium when it has zero acceleration.

$$\sum F_x = 0$$

$$\sum F_y = 0$$

Reasoning Strategy

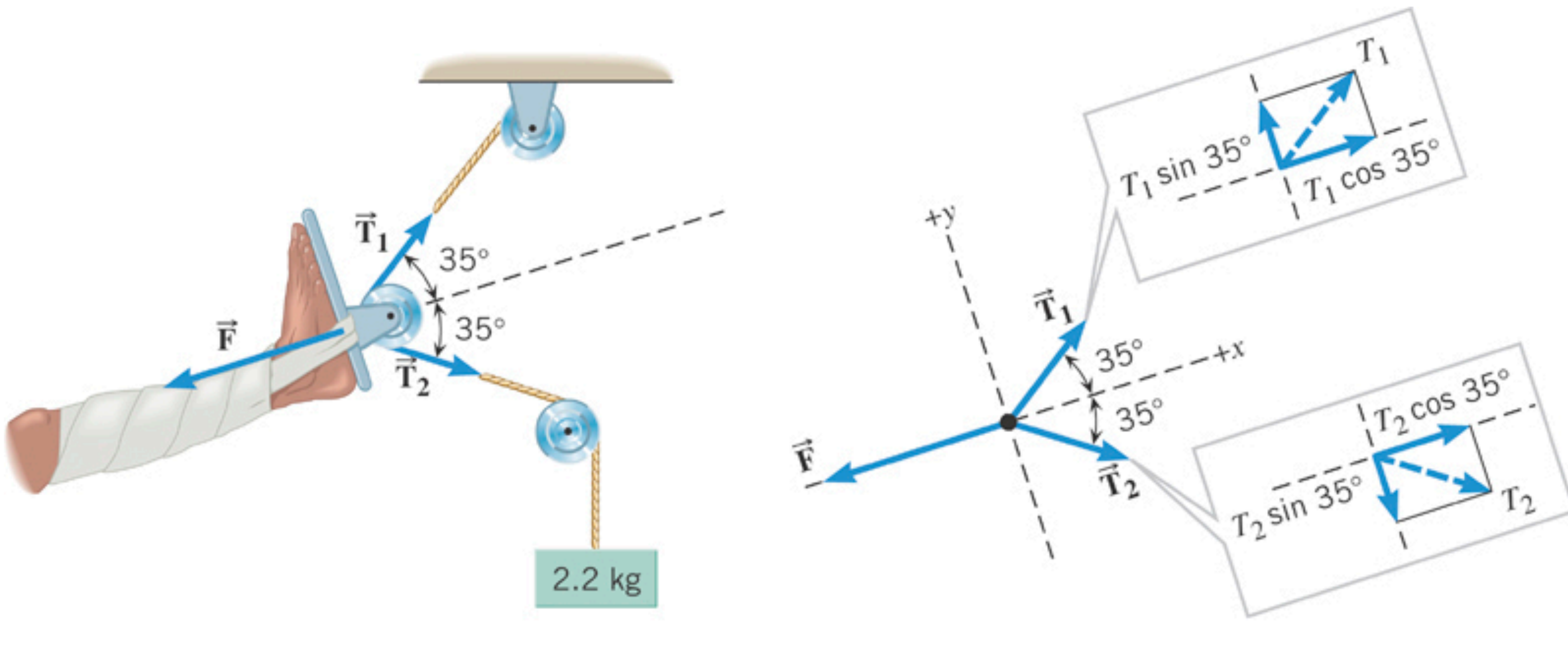
• Select an object(s) to which the equations of equilibrium are to be applied.

• 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



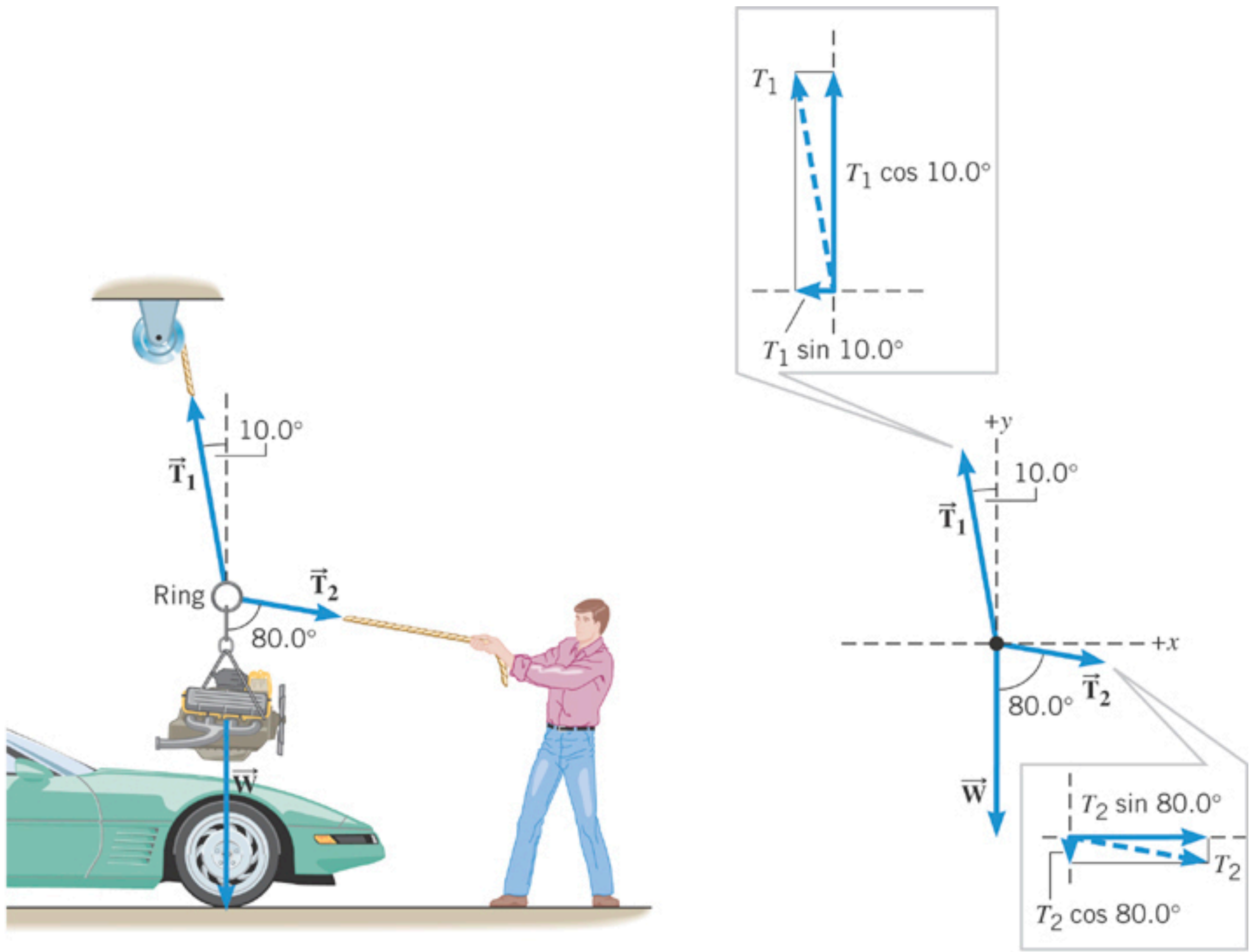
(a)

(b) Free-body diagram for the foot pulley

$$+T_1 \sin 35^\circ - T_2 \sin 35^\circ = 0$$

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

4.11 Equilibrium Application of Newton's Laws of Motion



(a) (b) Free-body diagram for the ring

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	$-W$

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

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

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

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

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

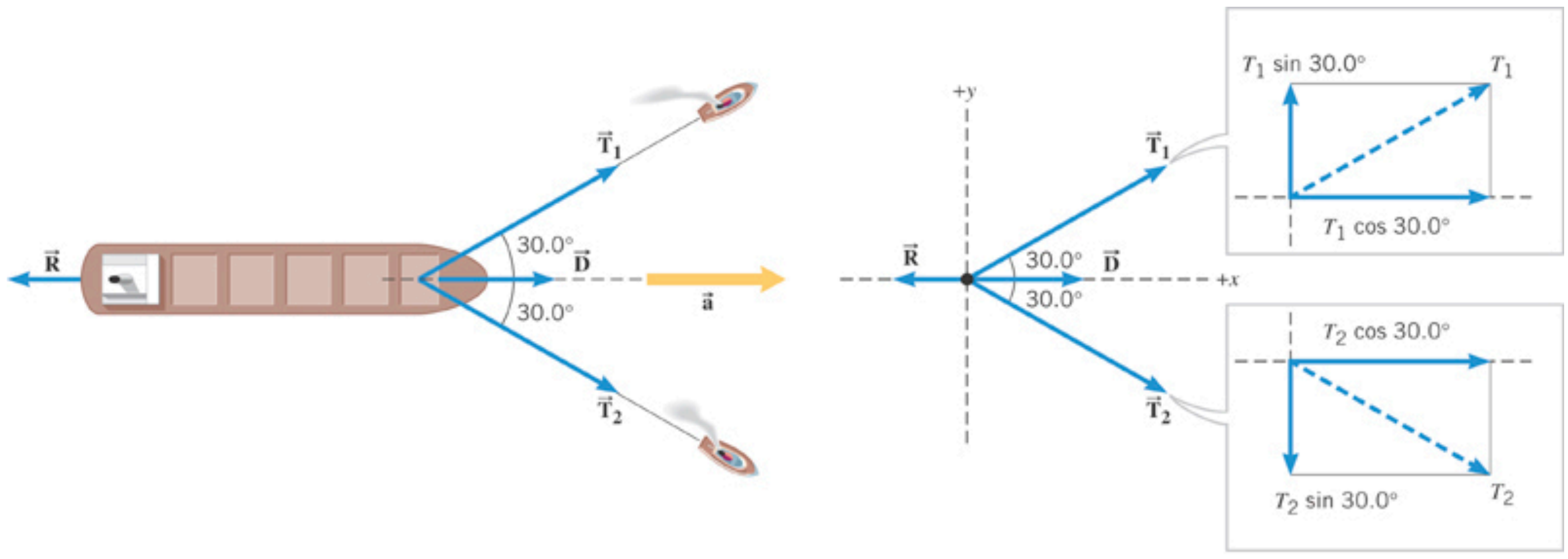
4.12 Nonequilibrium Application of Newton's Laws of Motion

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

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

$$\Rightarrow T_1 = T_2$$

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

$$= ma_x$$

$$T_1 = T_2 = T$$

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