

Chapter 4

Forces and Newton's Laws of Motion

continued

4.2 *Newton's Laws of Motion (Third Law)*

Newton's Third Law of Motion

Whenever **one body** exerts a force on a **second body**, the second body exerts an oppositely directed force of equal magnitude on the first body.

There are **2 and ONLY 2** objects involved in applying Newton's 3rd law, with 1 force acting **on each object**.

4.2 *Newton's Laws of Motion (Third Law)*

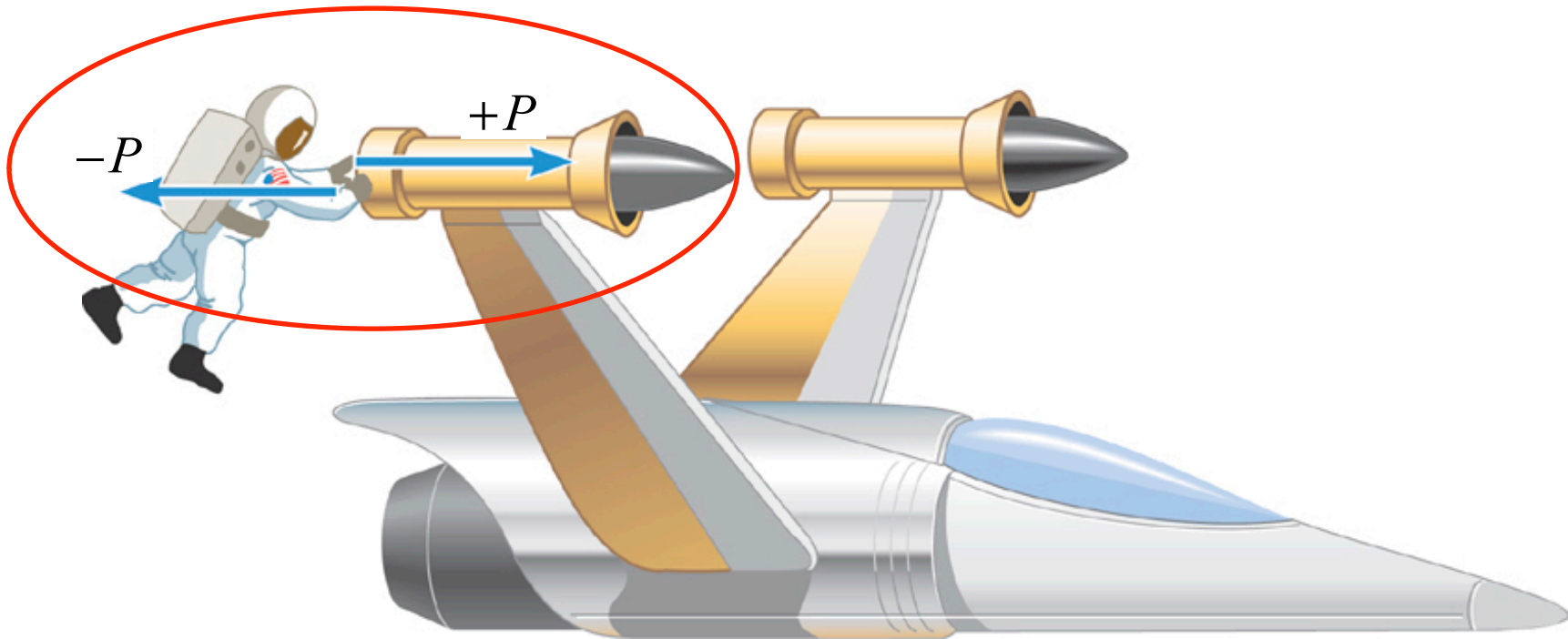
Warning:

Newton's 3st law can **appear** to be violated if you can't see the resulting movement of a massive object.

4.2 Newton's Laws of Motion (Third Law)

At the point of contact there are **two** forces generated:

1. Astronaut “pushes” on the spacecraft.
2. Spacecraft “responds” by pushing on the Astronaut.



Suppose that the magnitude of the force, $P = 36$ N. If the mass of the spacecraft is 11,000 kg and the mass of the astronaut is 92 kg, what are the accelerations?

4.2 Newton's Laws of Motion (Third Law)

On the **Spacecraft** $\sum F_{x,S} = +P$. (on one object)

On the **Astronaut** $\sum F_{x,A} = -P$. (on a second object)

The two forces have equal magnitudes and opposite directions, one on each object.

Spacecraft acceleration:

$$a_{x,S} = \frac{+P}{m_S} = \frac{+36 \text{ N}}{11,000 \text{ kg}} = +0.0033 \text{ m/s}^2$$

Really tiny, hard to notice
except over a very long time

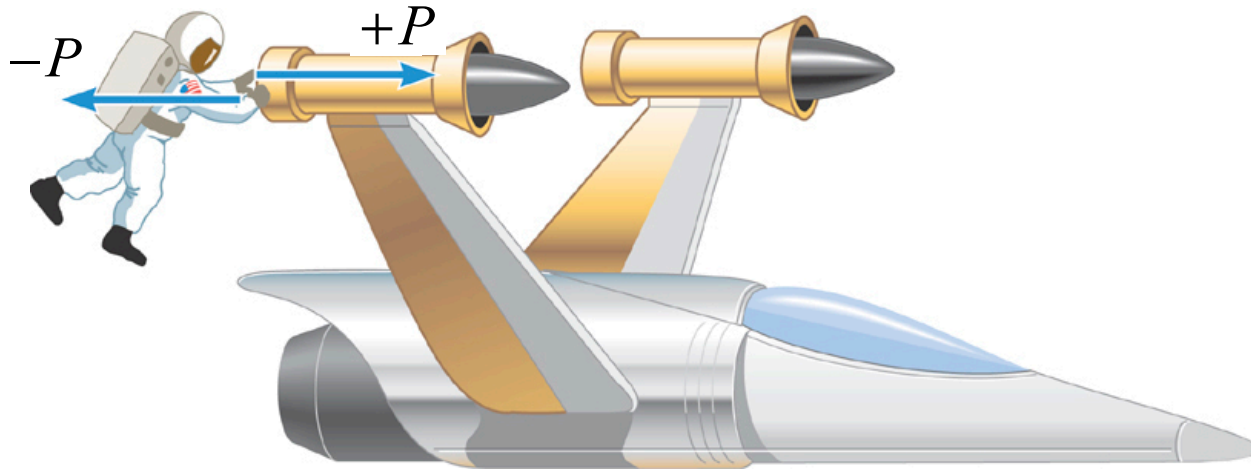
Astronaut acceleration:

$$a_{x,A} = \frac{-P}{m_A} = \frac{-36 \text{ N}}{92 \text{ kg}} = -0.39 \text{ m/s}^2$$

~100 times bigger

4.2 Newton's Laws of Motion (Third Law)

As soon as the astronaut's arms are fully extended, the contact with the spacecraft **is lost and FORCES vanish**.



Suppose contact is maintained for **1 second**. How fast will each object be moving? Both start at rest.

Spacecraft: $v_{x,S} = a_{x,S}t = +0.0033 \text{ m/s} (= 3.3 \text{ mm/s})$ **Tiny speed**

Astronaut: $v_{x,A} = a_{x,A}t = -0.39 \text{ m/s}$ **>100 times larger speed.**

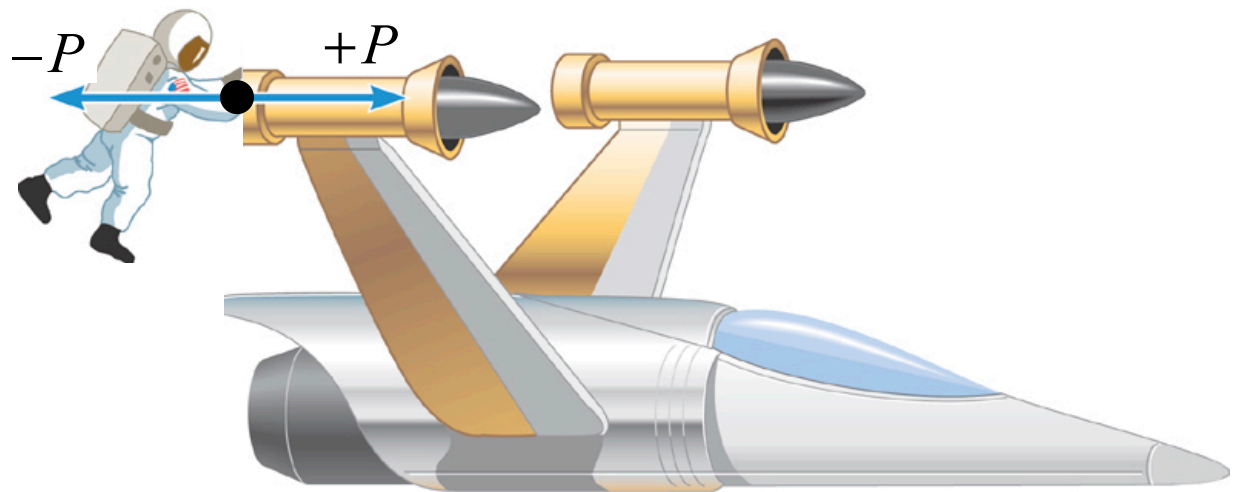
4.2 Newton's Laws of Motion (Third Law)

These two forces **do NOT have** a Net Force = 0!

Net force has no meaning for forces acting on different objects.

Spacecraft's push
acting **on** the astronaut.

Astronaut's push
acting **on** spacecraft

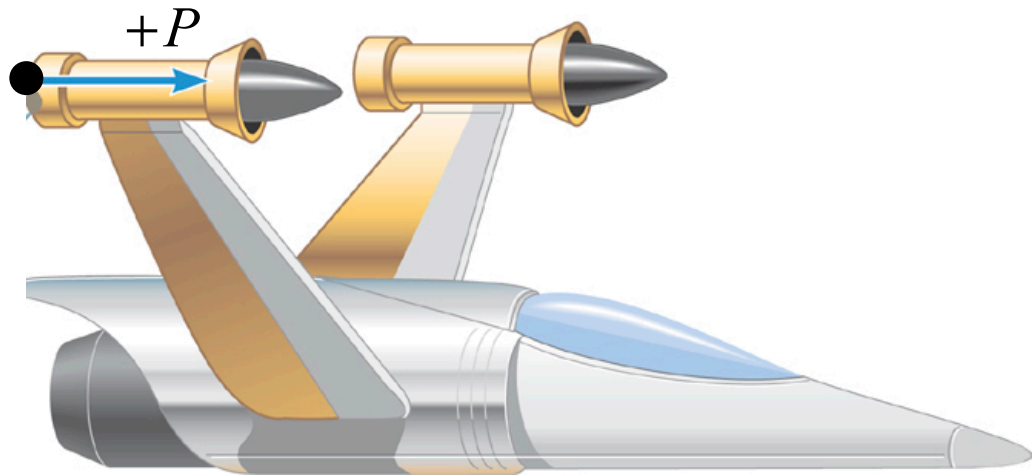


4.2 *Newton's Laws of Motion (Third Law)*

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Astronaut's push
acting **on** spacecraft

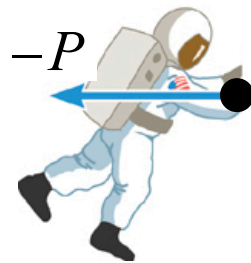


4.2 Newton's Laws of Motion (Third Law)

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Spacecraft's push acting **on** the astronaut.



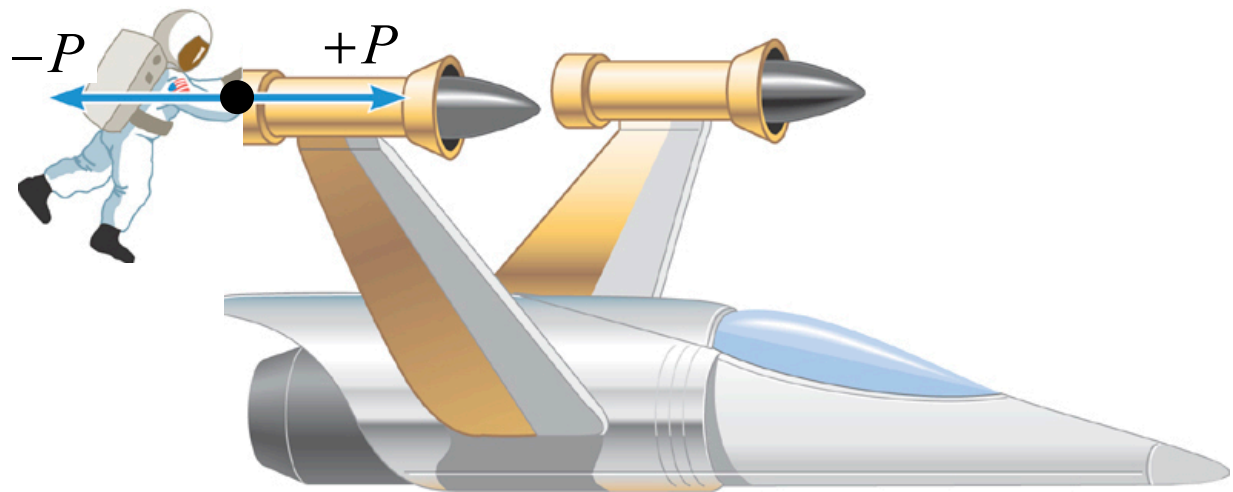
4.2 Newton's Laws of Motion (Third Law)

These two forces **do NOT have** a Net Force = 0!

Net force has no meaning for forces acting on different objects.

Spacecraft's push
acting **on** the astronaut.

Astronaut's push
acting **on** spacecraft



4.2 *Newton's Laws of Motion (Third Law)*

Examples & Clicker Questions
on Newton's Third Law.

Ball bouncing off a **wall**.

Mass sliding w/friction on heavy **table**.

Bat hitting a **baseball**

Gun firing a **bullet**

Bat hitting a baseball

Newton's 3rd law: Whatever magnitude of force the bat applies to the ball, the ball applies the same magnitude of force back (opposite direction) onto the bat.

The bat is slowed by the force of the ball on the bat, and the ball is accelerated by the force of the bat

A gun firing a bullet

Newton's 3rd law: Whatever force the explosion applies to the bullet, it applies an equal magnitude force back (opposite direction) onto the gun.

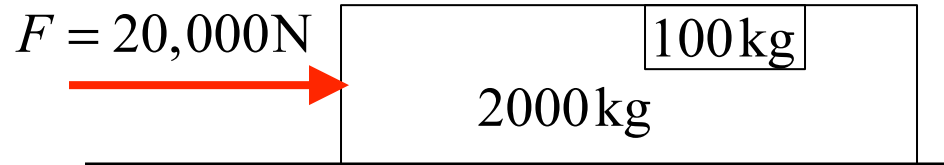
The bullet is accelerated by the force of the explosion, and the gun is accelerated in the opposite direction by the same magnitude of force.

Applications of Newton's Laws

Example exam question

A car with a mass of 2000 kg and its driver with a mass of 100 kg, are accelerated by a force of 20,000 N. What force accelerates the driver?

- a) 200 N
- b) 2000 N
- c) 9.5 N
- d) 100 N
- e) 950 N



Acceleration is the same for car and driver

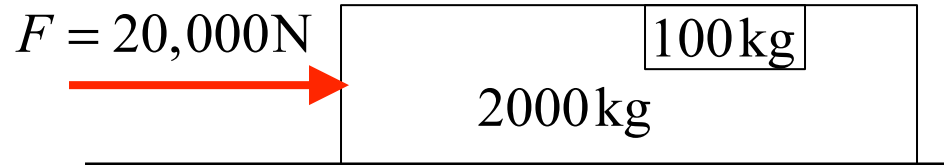
Use $\vec{F} = m\vec{a}$ (twice)

- 1) **Determine the acceleration for both masses**
- 2) **then force on only driver (use driver mass)**

Example exam question

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Acceleration is the same for car and driver

Use $\vec{F} = m\vec{a}$ (twice)

- 1) **Determine the acceleration for both masses**
- 2) **then force on only driver (use driver mass)**

$$m_{\text{Car}} + m_{\text{Driver}} = 2100 \text{ kg}$$

$$a = \frac{F_{C\&D}}{m_{C\&D}} = \frac{20,000 \text{ N}}{2100 \text{ kg}} = 9.5 \text{ m/s}^2; \text{ for car \& driver.}$$

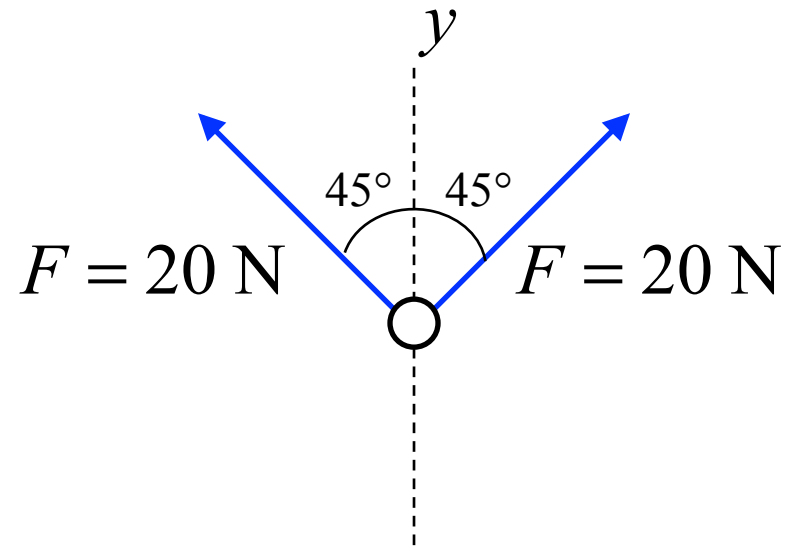
Force on the driver -

$$F_D = m_D a = (100 \text{ kg})(9.5 \text{ m/s}^2) = \underline{950 \text{ N}}$$

Example:

Acting on a ball are two forces, each with a magnitude of 20 N, acting at 45° with the respect to the vertical direction. What additional force will make the Net Force acting on the ball equal to zero?

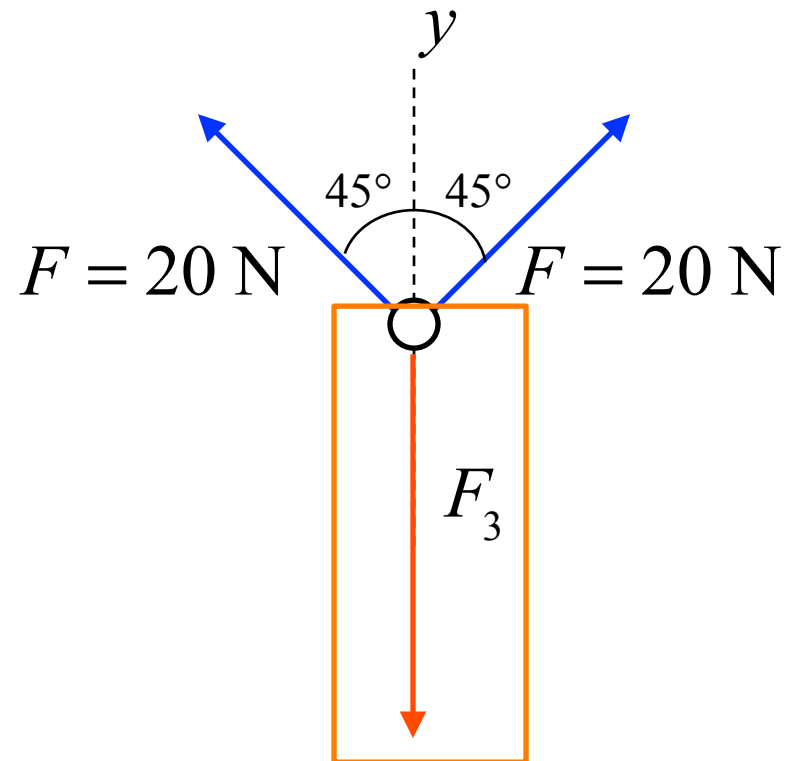
- a) -40 N
- b) -14 N
- c) -32 N
- d) -18 N
- e) -28 N



Example:

Acting on a ball are two forces, each with a magnitude of 20 N, acting at 45° with the respect to the vertical direction. What additional force will make the Net Force acting on the ball equal to zero?

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Example:

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Find y-component of each force

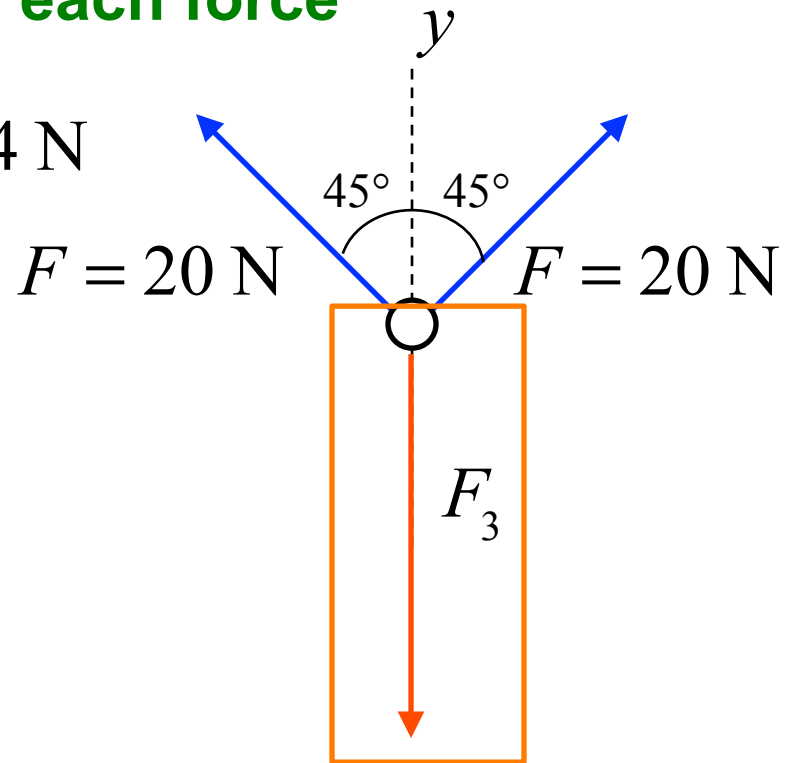
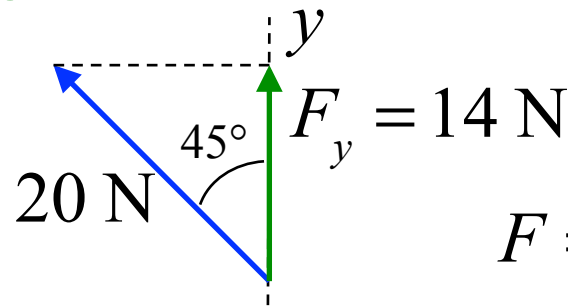
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Example:

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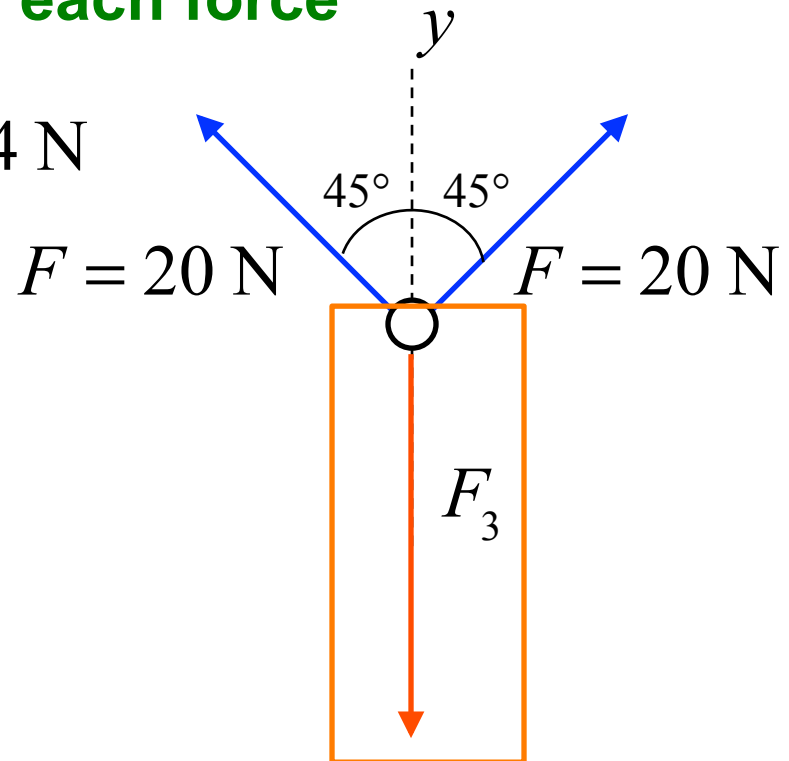
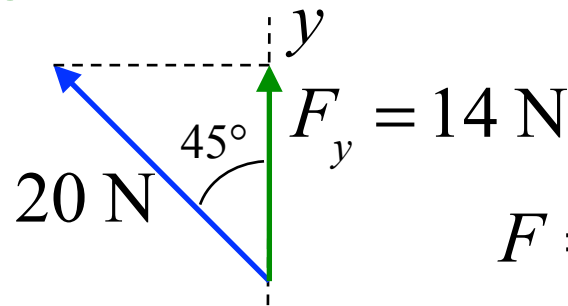
a) -40 N

b) -14 N

c) -32 N

d) -18 N

e) -28 N



$$y: F_{Net} = 0 = 2(F \cos 45^\circ) + F_3$$

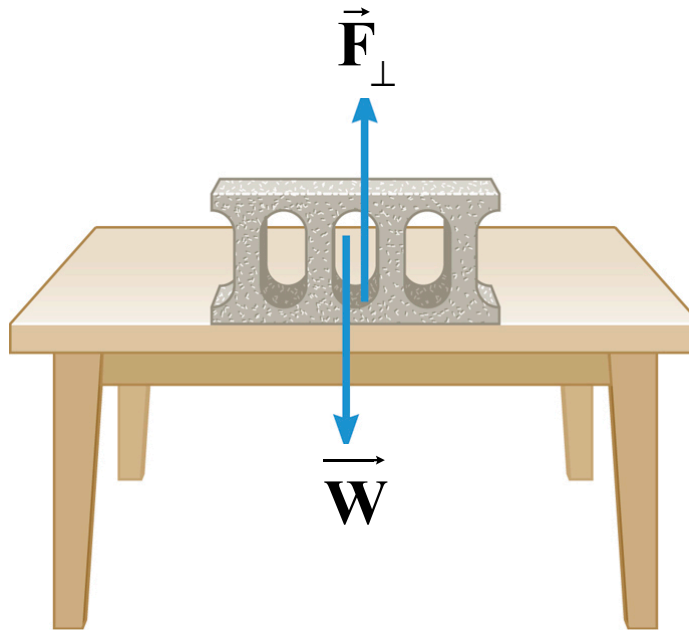
$$F_3 = -2(F \cos 45^\circ) = -28\text{ N}$$

4.3 Applications Newton's Laws (Normal Forces)

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.

$\vec{F}_{\perp}$ sometimes written as $\vec{n}$



4.3 Applications Newton's Laws (Normal Forces)

A block with a weight of 15 N sits on a table. It is pushed down with a force of 11 N or pulled up with a force of 11 N. Calculate the **normal force** in each case.

$$\vec{a} = 0 \Rightarrow \vec{F}_{\text{Net}} = 0$$

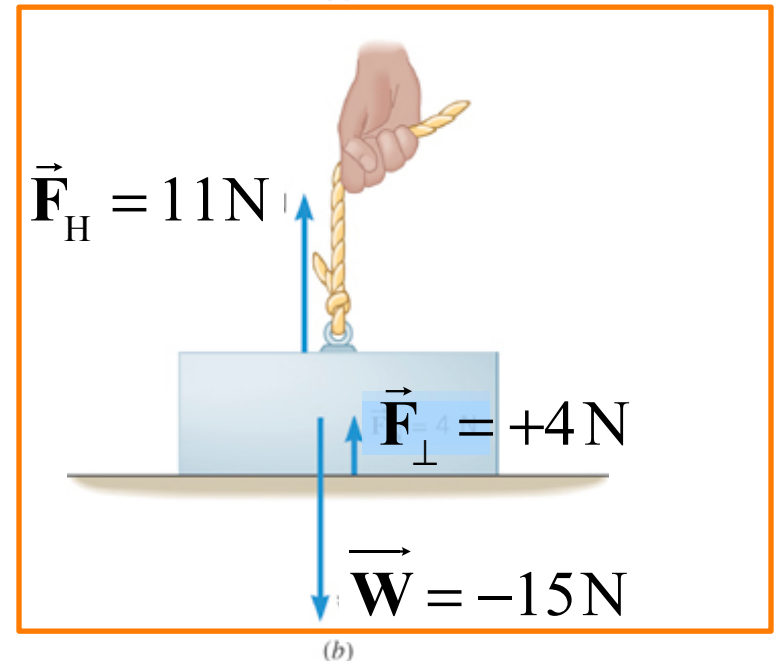
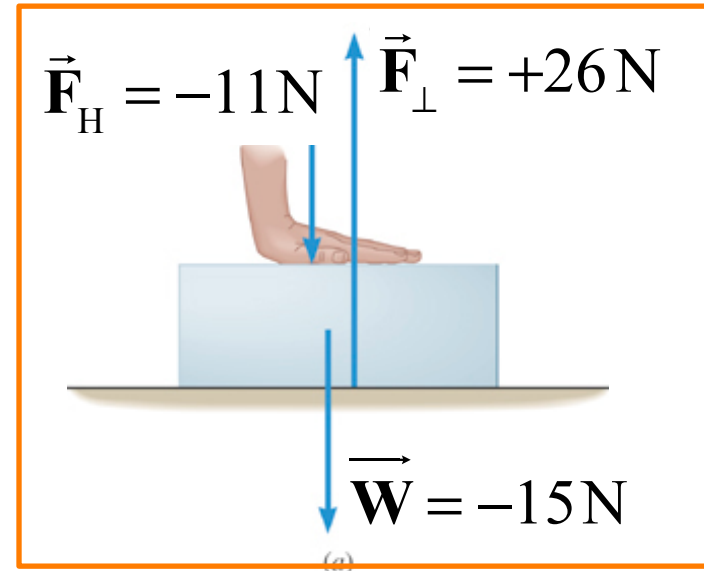
three forces
act on block

$$\vec{F}_{\text{Net}} = \vec{F}_{\perp} + \vec{F}_H + \vec{W} = 0$$

$$\begin{aligned}\vec{F}_{\perp} &= -\vec{F}_H - \vec{W} \\ &= -(-11\text{N}) - (-15\text{N}) \\ &= +26\text{ N}\end{aligned}$$

$$\vec{F}_{\text{Net}} = \vec{F}_{\perp} + \vec{F}_H + \vec{W} = 0$$

$$\begin{aligned}\vec{F}_{\perp} &= -\vec{F}_H - \vec{W} \\ &= -(11\text{N}) - (-15\text{N}) \\ &= +4\text{ N}\end{aligned}$$



4.3 Newton's Laws of Motion (Elevators)

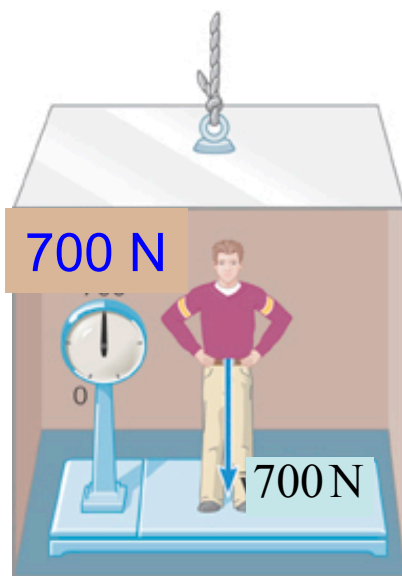
Apparent Weight = Normal force acting on an object

The **Apparent Weight** of an object is the value the scale reads.

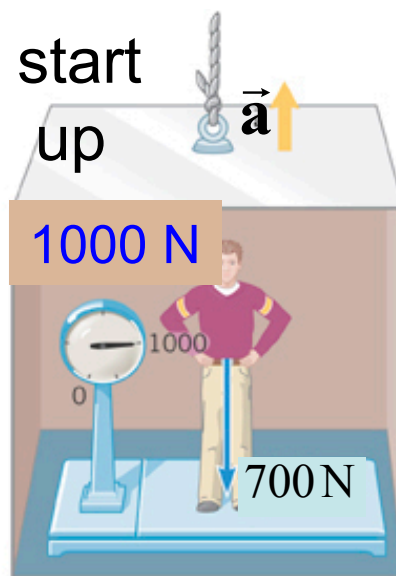
Apparent Weight = normal force of the scale on the person.

Also, by Newton's 3rd law

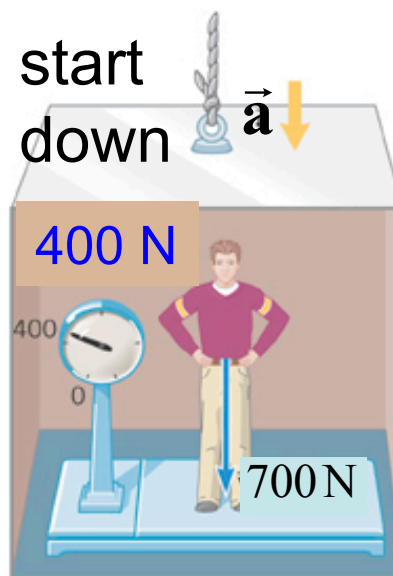
Apparent Weight = normal force of the person on the scale.



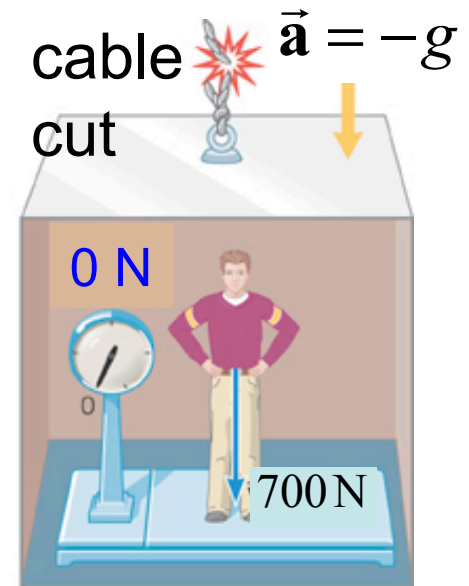
v constant
up/down/zero



accelerating
 a , upward



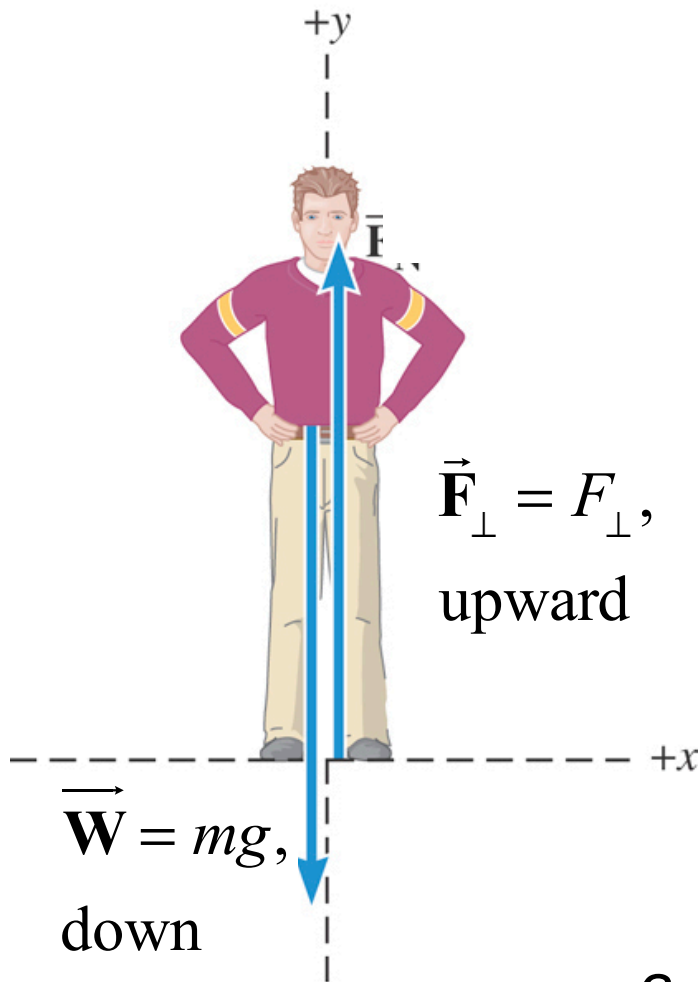
accelerating
 a , downward



Free fall
 $a = g$, downward

4.3 Newton's Laws of Motion (Normal Forces)

For the person being accelerated (a)



$$\sum F_y = F_\perp + W = ma_y$$

$$F_\perp = -W + ma_y$$

$$F_\perp = mg + ma_y$$

apparent
weight

true
weight

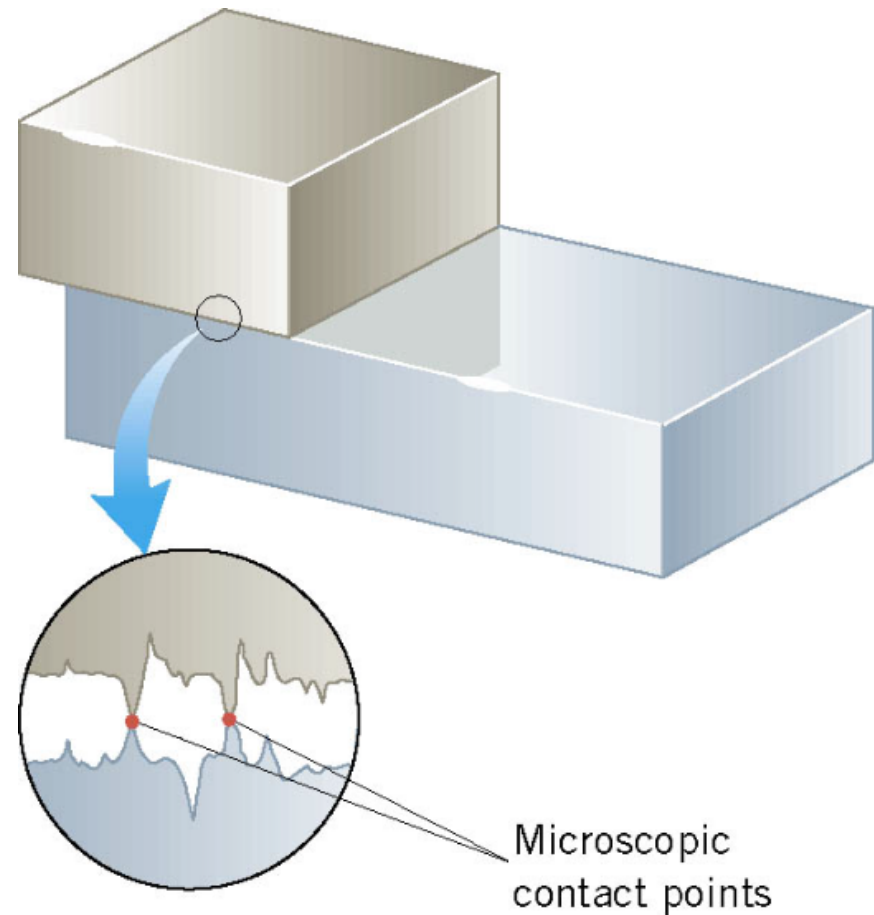
a_y is up: apparent weight > true weight

a_y is down: apparent weight < true weight

$a_y = 0$, constant velocity: apparent weight = true weight

4.4 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***.



4.4 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 is zero on block

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

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

$$F_R = f_s \text{ (same magnitude)}$$

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

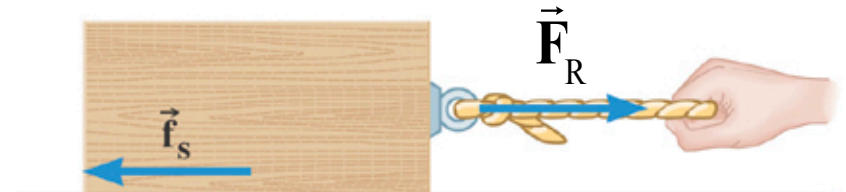
Until the static frictional force f_s reaches its maximum value, f_s^{Max} , and the block begins to slide.

$\vec{F}_R$ = rope force



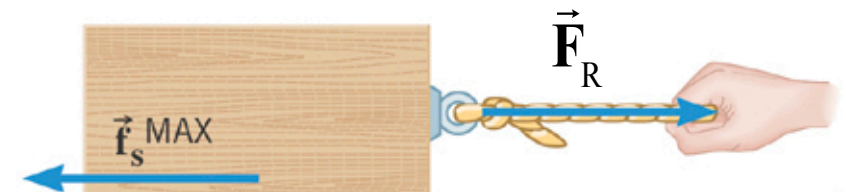
No movement

$\vec{f}_s$ = static friction force



No movement

(b)



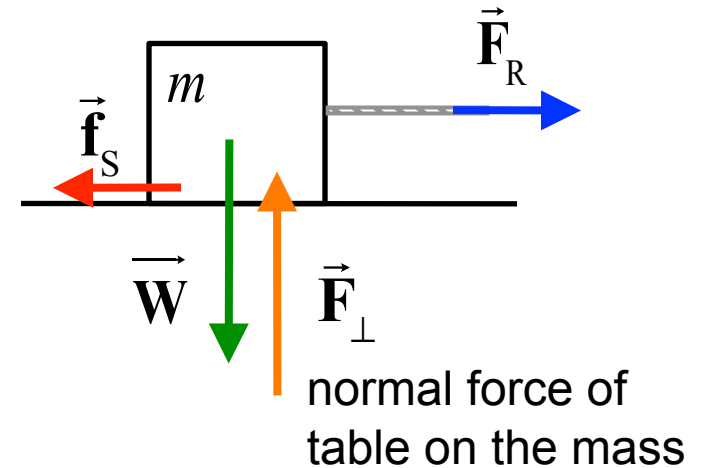
When movement just begins

(c)

4.4 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.



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

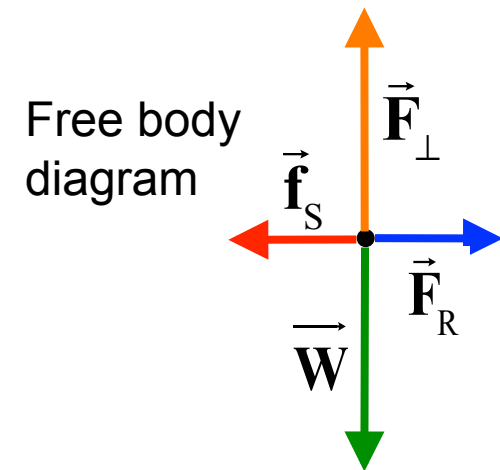
$$f_s^{\text{Max}} = \mu_s F_\perp,$$

$$0 < \mu_s < 1$$

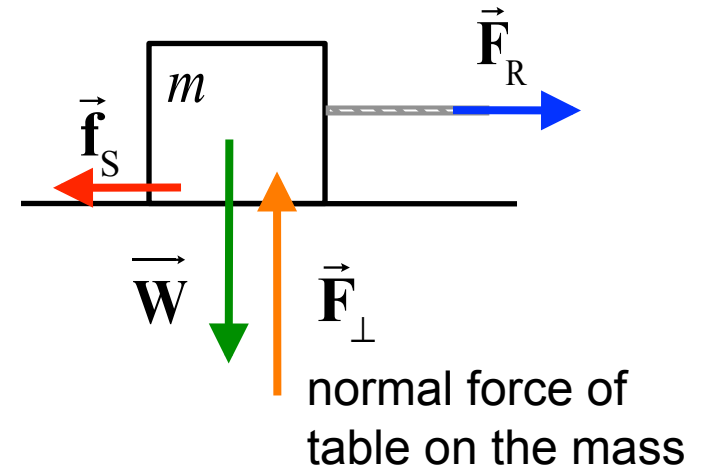
Vertical forces only

$$F_\perp = W = mg$$

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?

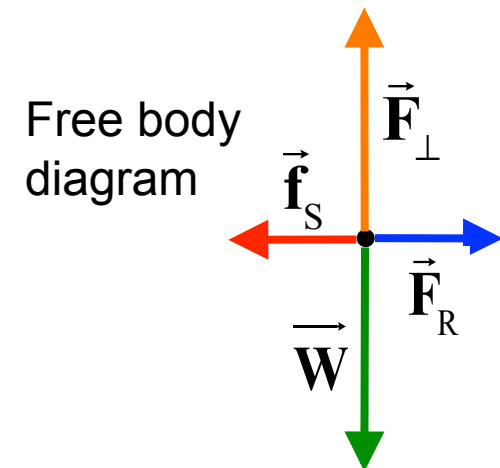


$$W = mg = 49,000 \text{ N (magnitude)}$$

$$f_S^{\text{Max}} = F_R = 10,000 \text{ N (magnitude)}$$

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

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



4.4 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.

4.4 Static and Kinetic Frictional Forces

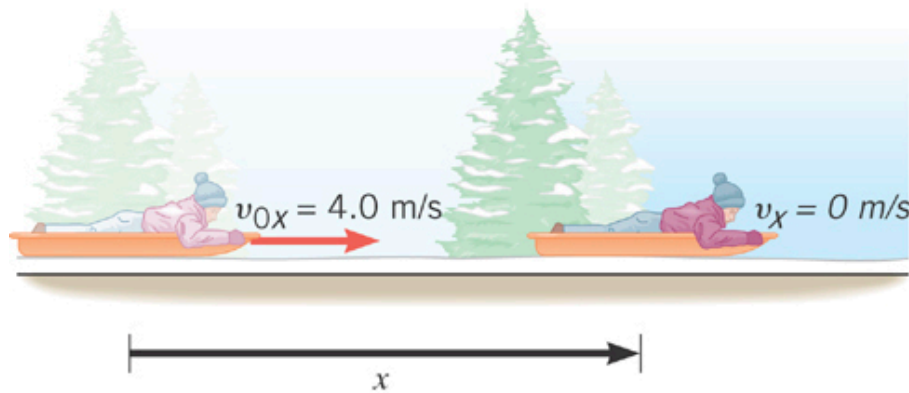
Table 4.2 Approximate Values of the Coefficients of Friction for Various Surfaces*

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

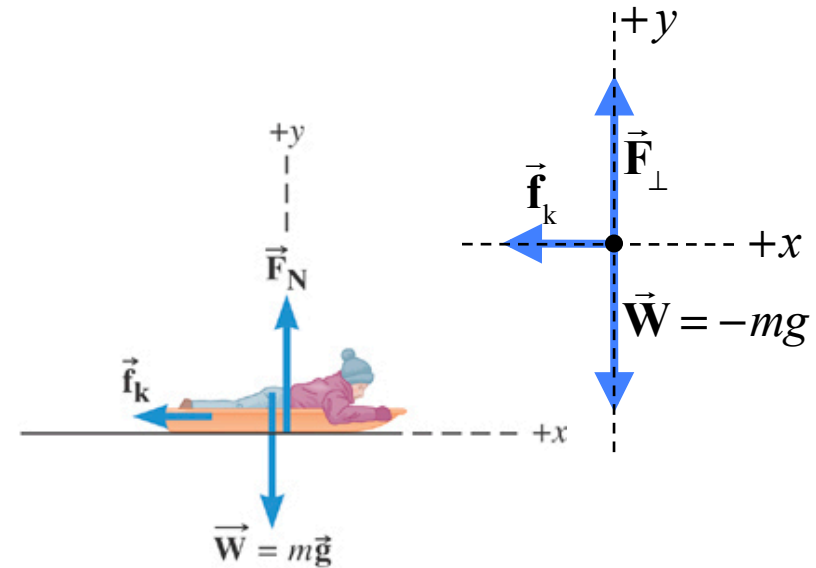
*The last column gives the coefficients of kinetic friction, a concept that will be discussed shortly.

4.4 Static and Kinetic Frictional Forces

Free Body Diagram



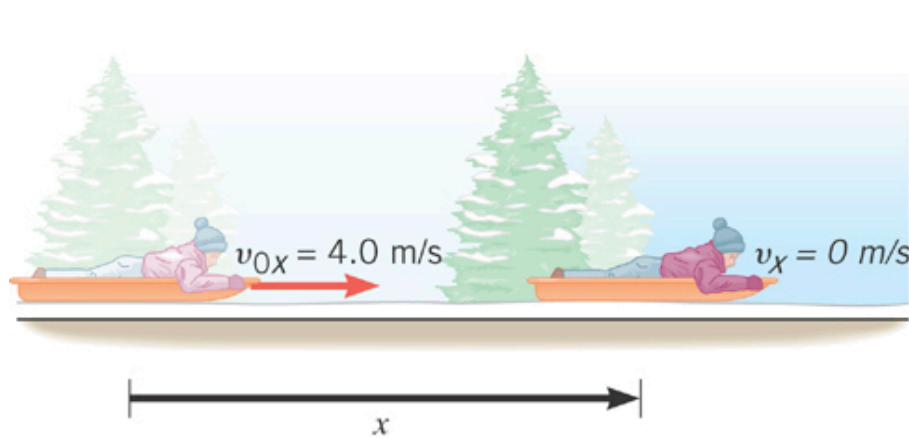
(a)



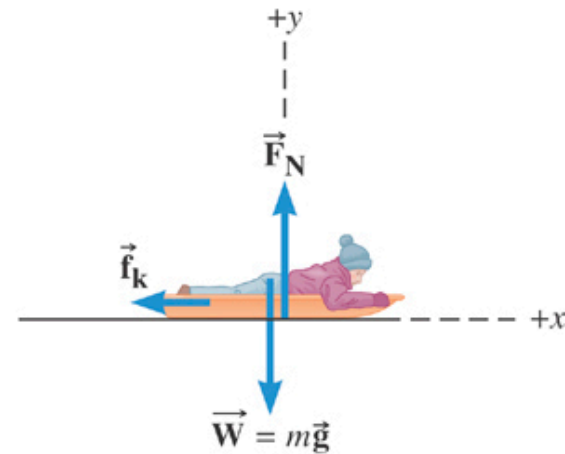
(b) Free-body diagram
for the sled and rider

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

4.4 Static and Kinetic Frictional Forces



(a)



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

Suppose the coefficient of kinetic friction is 0.050 and the total mass is 40.0kg. What is the kinetic frictional force?

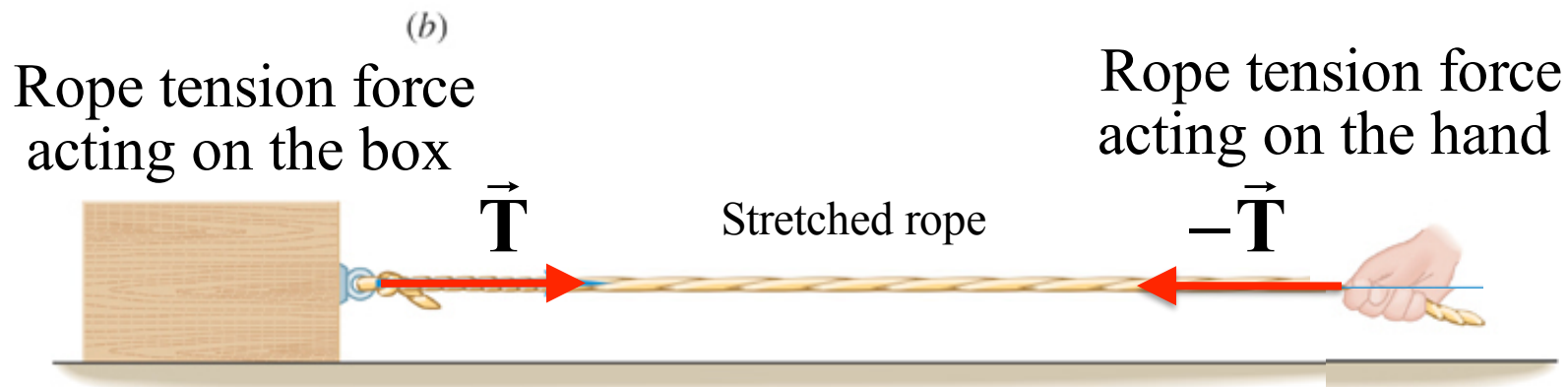
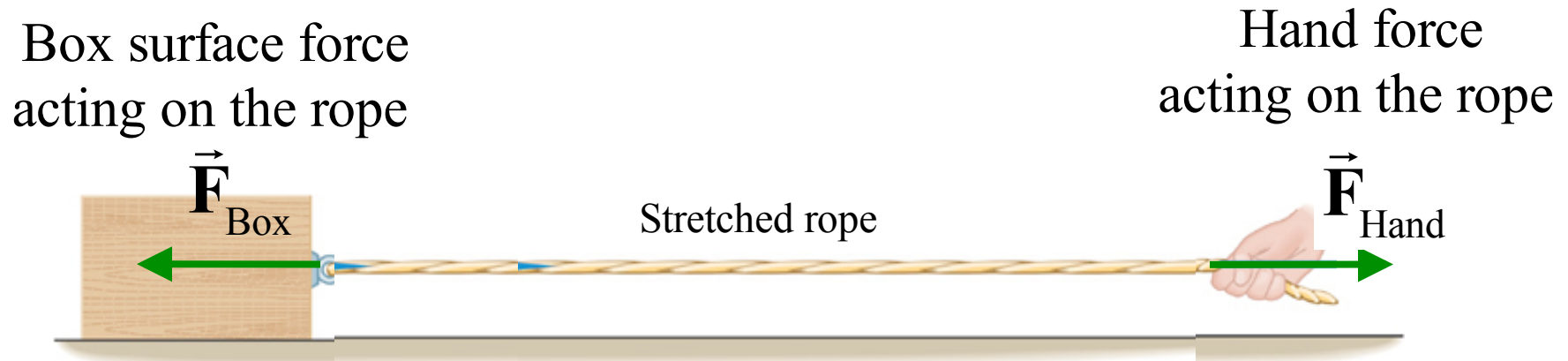
$$f_k = \mu_k F_N$$

Friction equations are
for MAGNITUDES only.

$$= \mu_k mg = 0.050(40.0\text{kg})(9.81\text{m/s}^2) = 19.6 \text{ N}$$

4.4 The Tension Force

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

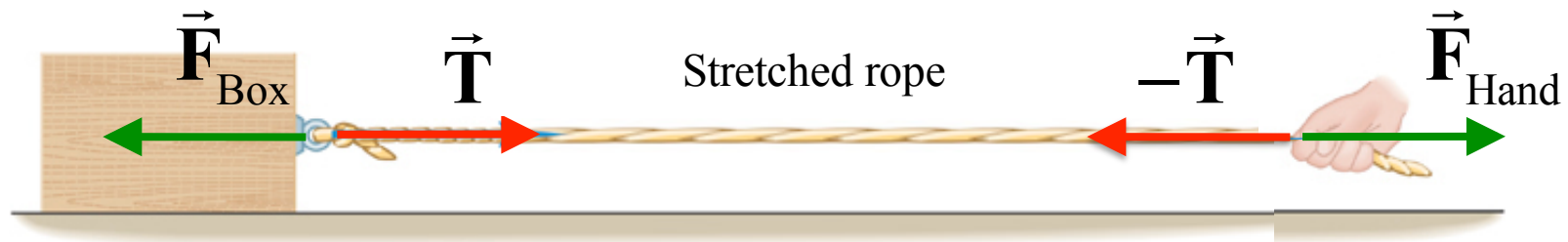


$(\vec{F}_{\text{Box}}, \vec{T})$ These are Newton's 3rd law Action – Reaction pairs $(-\vec{T}, \vec{F}_{\text{Hand}})$

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

4.4 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 3rd law
Action – Reaction pairs

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

Tension pulls on box

Box pulls on rope

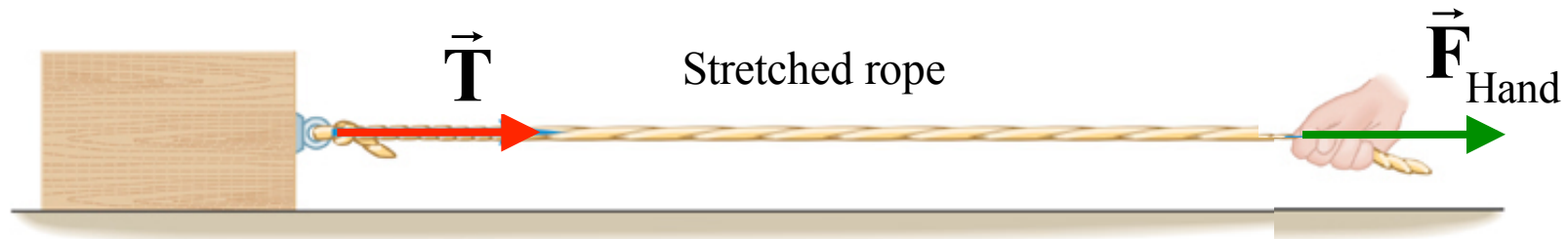
Tension pulls on hand

Hand pulls on rope

4.4 The Tension Force

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

These are the important forces

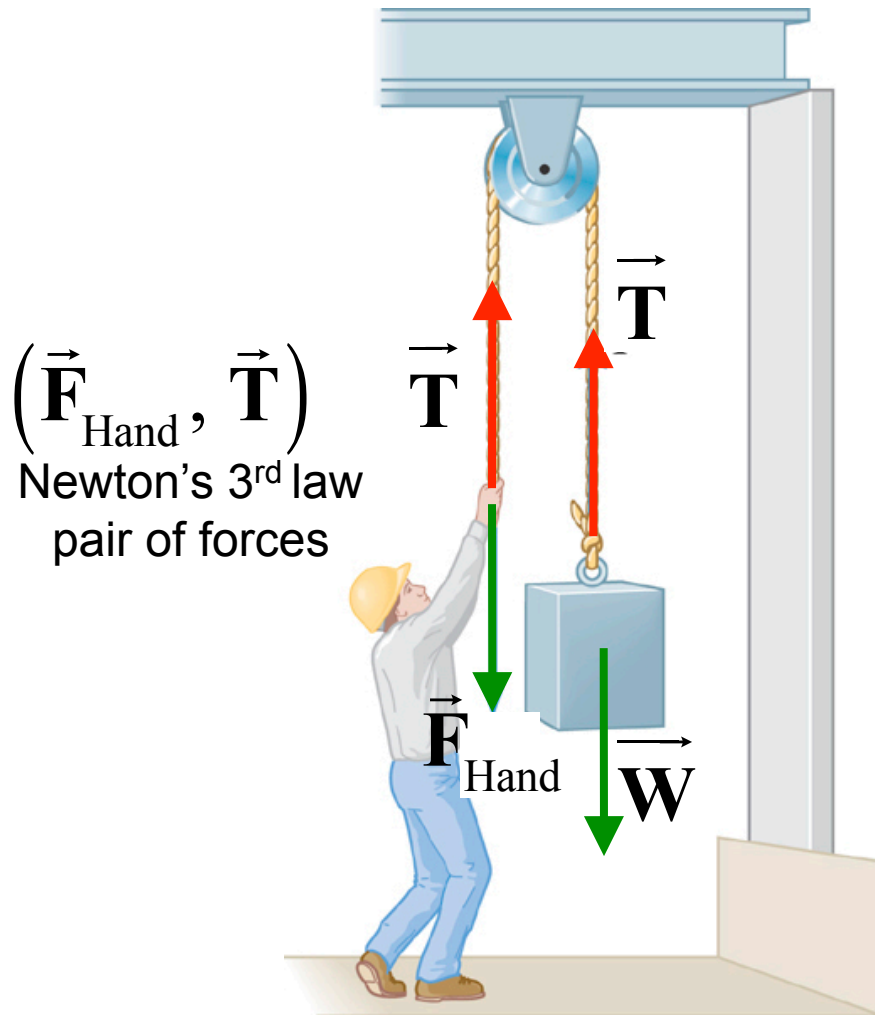


Hand force causes a tension force on the box

Force magnitudes are the same

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

4.4 The Tension Force



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!

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

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

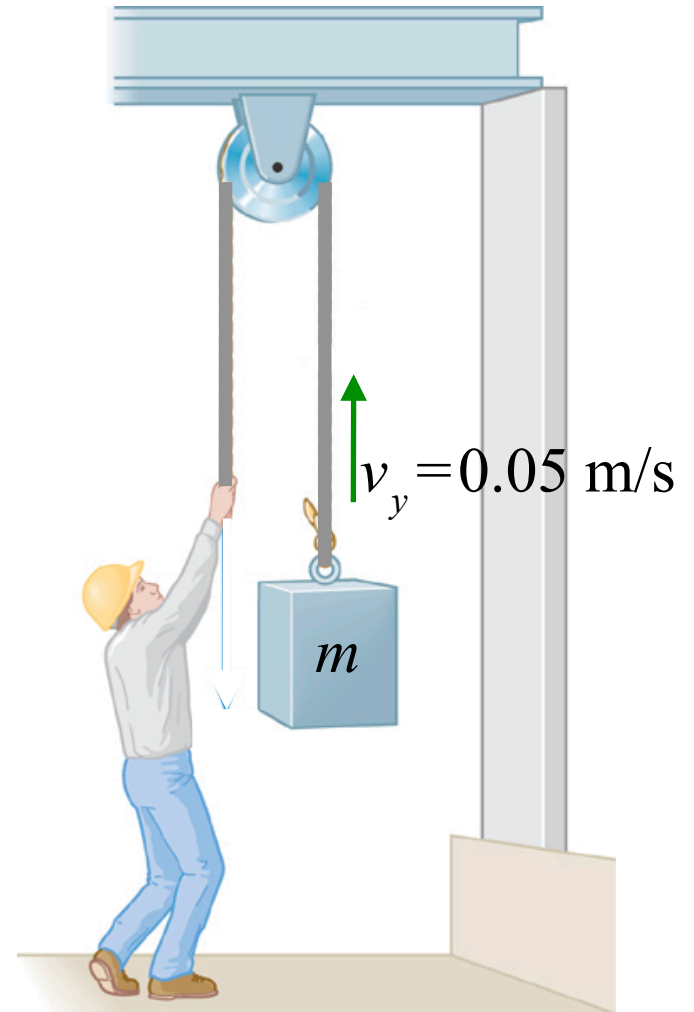
$$\vec{T} = +mg, \text{ and } \vec{F}_{\text{Hand}} = -mg$$

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

Example exam question

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

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



Example exam question

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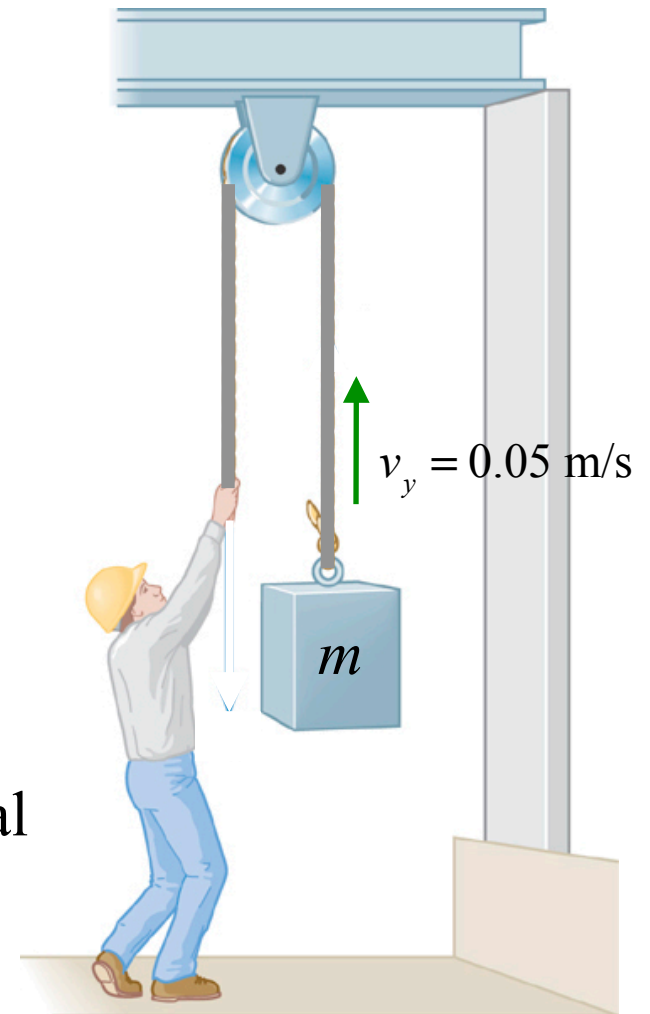
c) $< mg$

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 $= mg$.



4.4 *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

4.4 *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.

4.4 Equilibrium Application of Newton's Laws of Motion

Inclined plane and similar problems

