Chapter 4

Forces and Newton's Laws of Motion

continued

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)

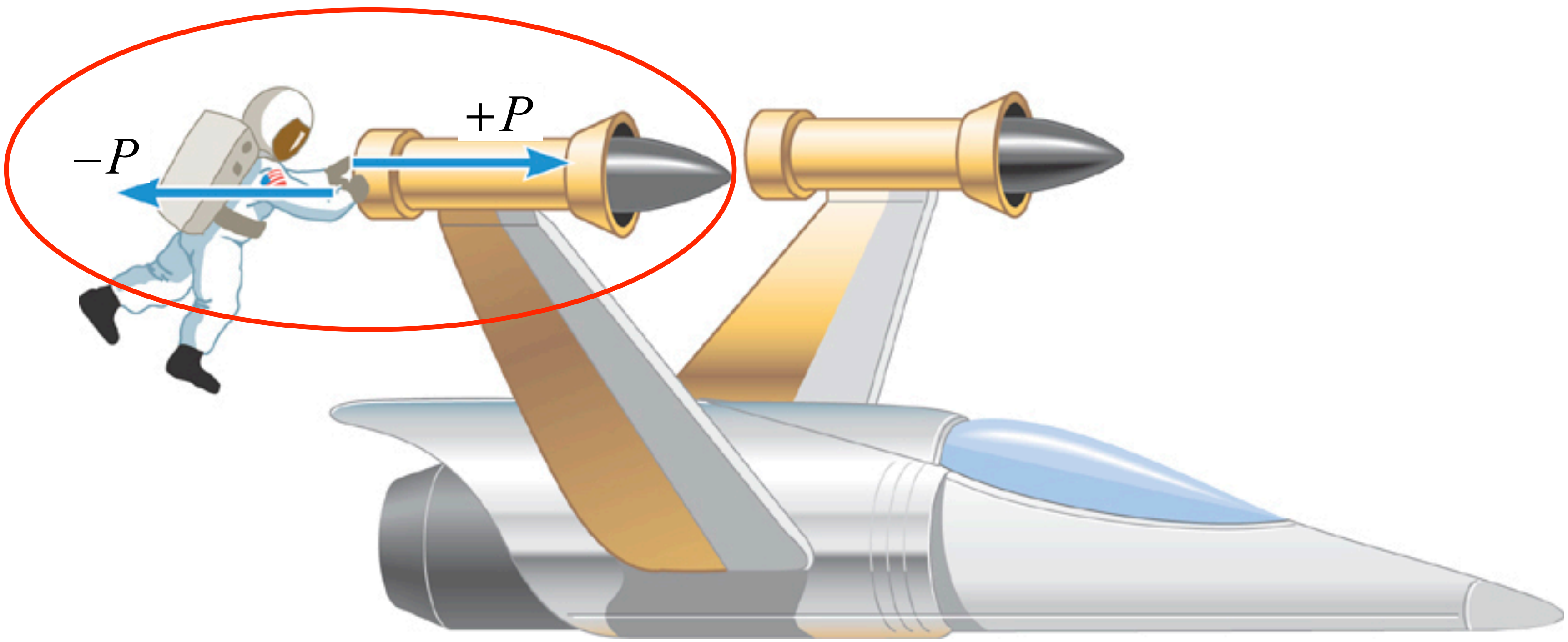
Warning:

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:

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

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

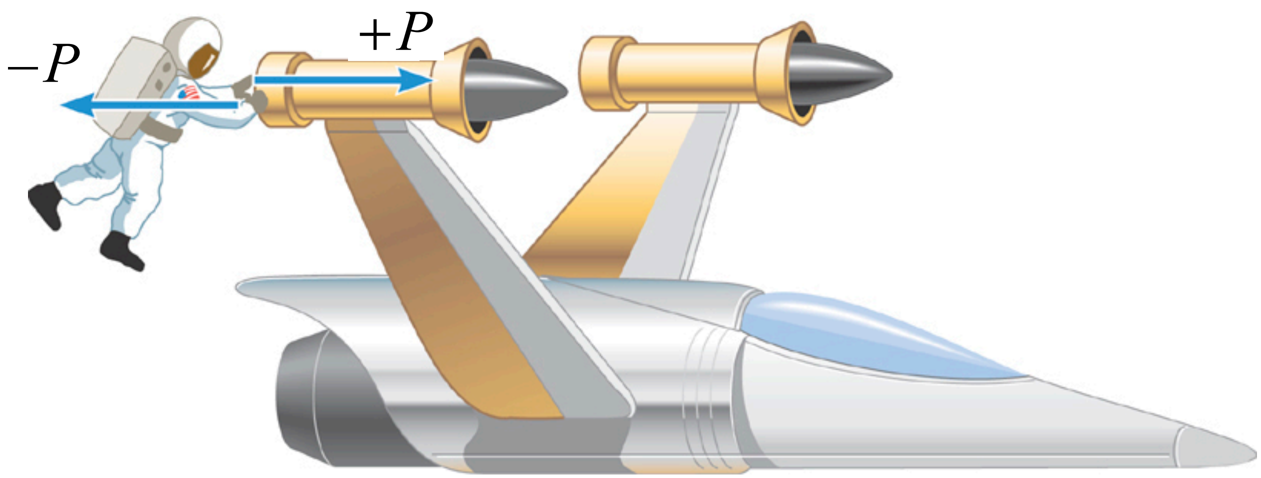
Astronaut acceleration:

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

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

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

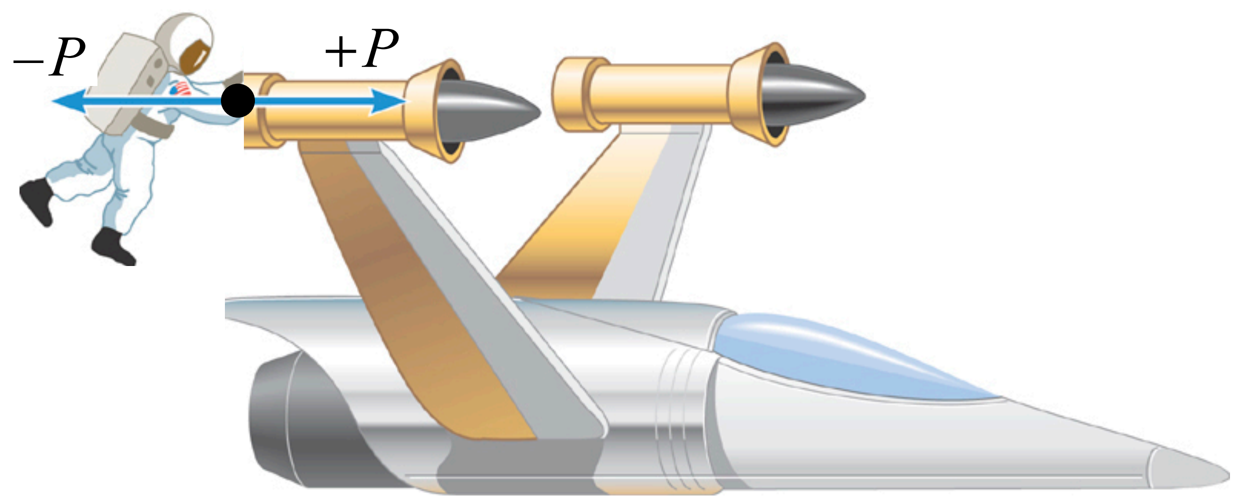
4.2 Newton's Laws of Motion (Third Law)

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



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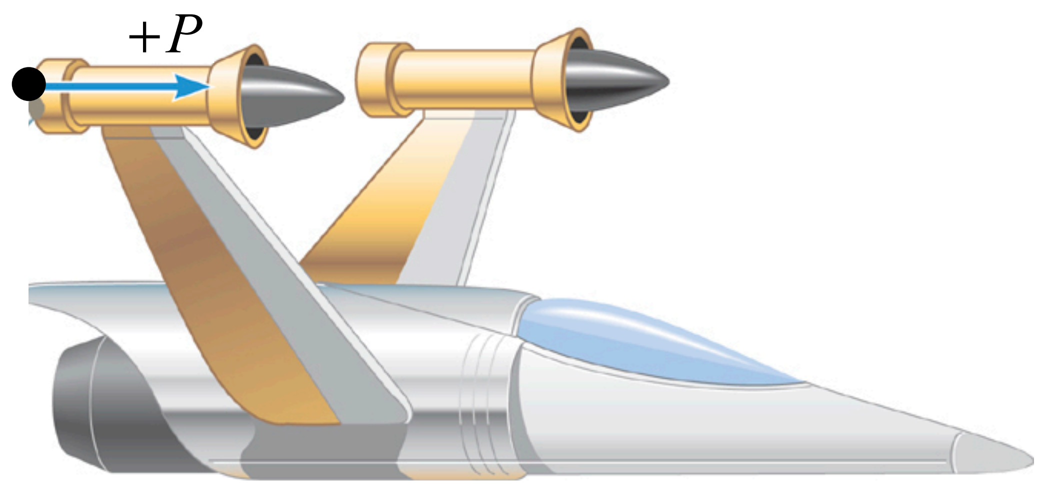
Astronaut's push acting on spacecraft



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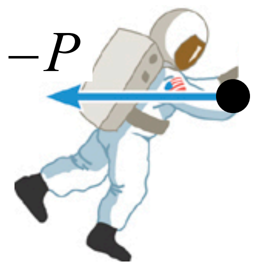
Spacecraft’s push acting on the astronaut.



4.2 Newton's Laws of Motion (Third Law)

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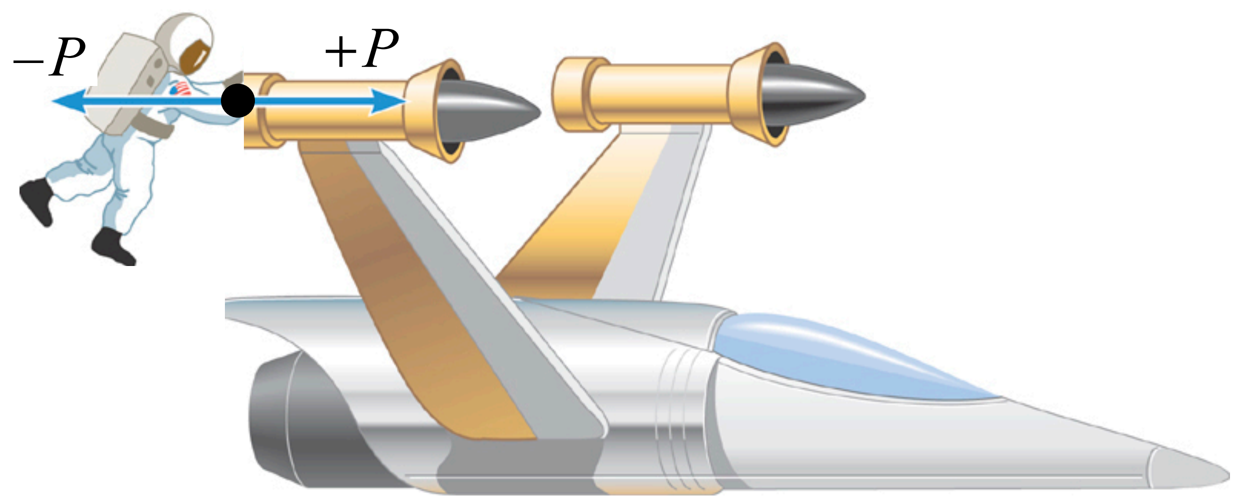
Spacecraft's push acting on the astronaut.

Astronaut's push acting on spacecraft

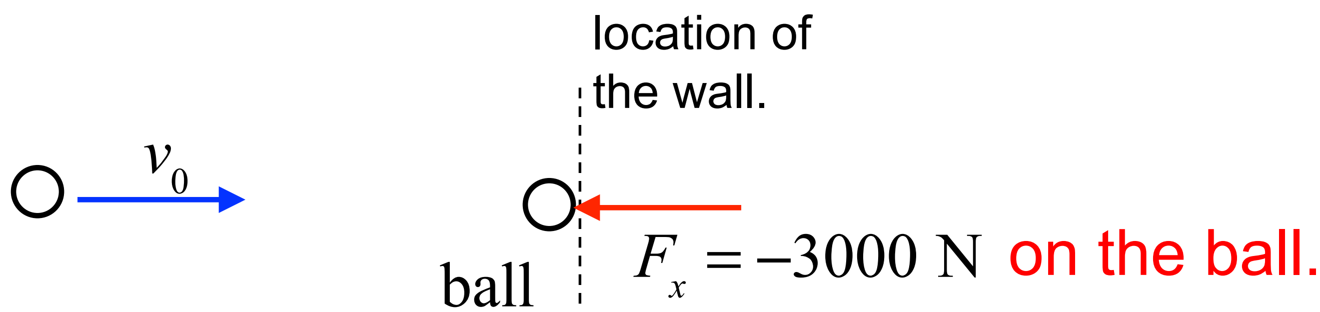


Examples & Clicker Questions
on Newton's Third Law.

Ball bouncing off a **wall**.
Mass sliding w/friction on heavy **table**.
Bat hitting a **baseball**
Gun firing a **bullet**

Clicker Question 4.7

A ball heads horizontally toward a wall. While in contact the wall applies a force, $F_x = -3000$ N on the ball, as shown. At the same time, the ball must apply what force on the wall?



a) $F_x = -3000$ N

b) $F_x = +3000$ N

c) $F_x = 0$ N

d) $F_x = 60$ N

e) A ball cannot make a force.

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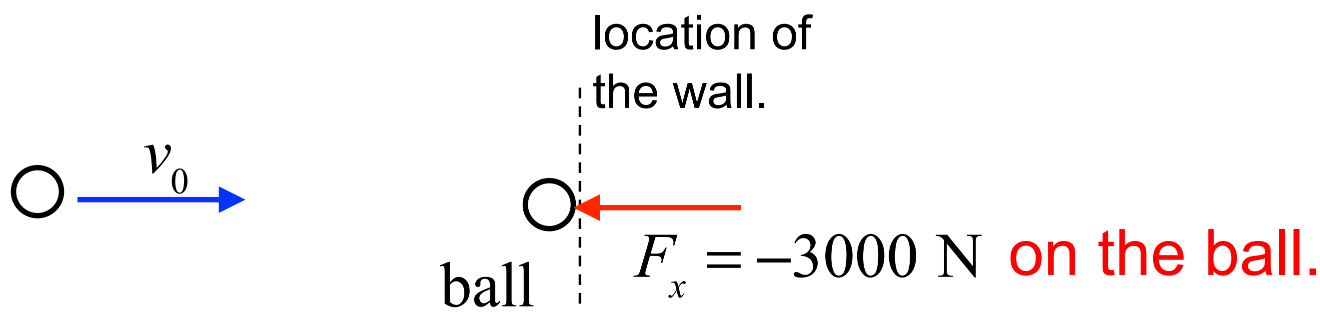

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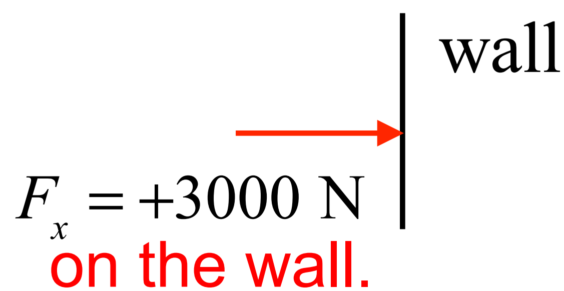
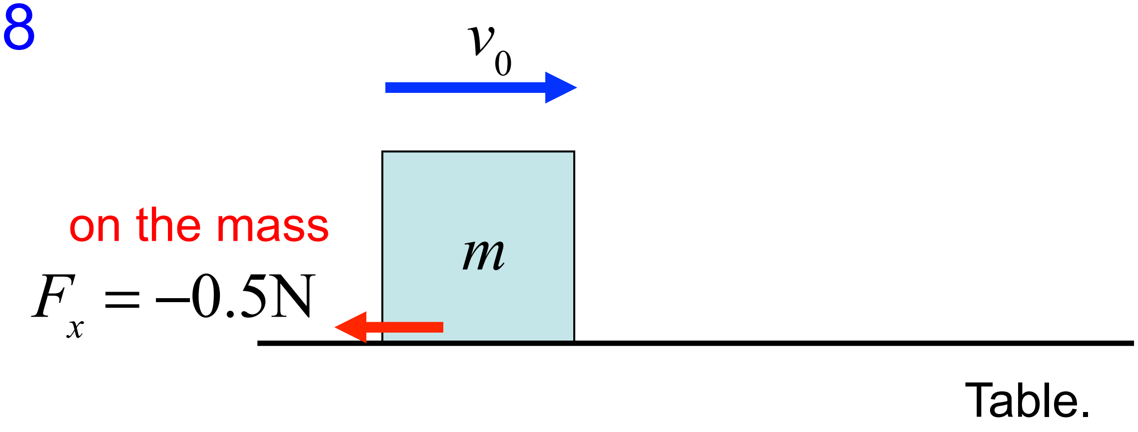


Clicker Question 4.8



While the mass is sliding, a friction force, $F_x = -0.5\,\text{N}$, acts on the mass. What friction force acts on the table, $F_{x,T}$?

a) $F_{x,T} = +0.5\,\text{N}$

b) $F_{x,T} = -0.5\,\text{N}$

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e) A mass cannot make a force.

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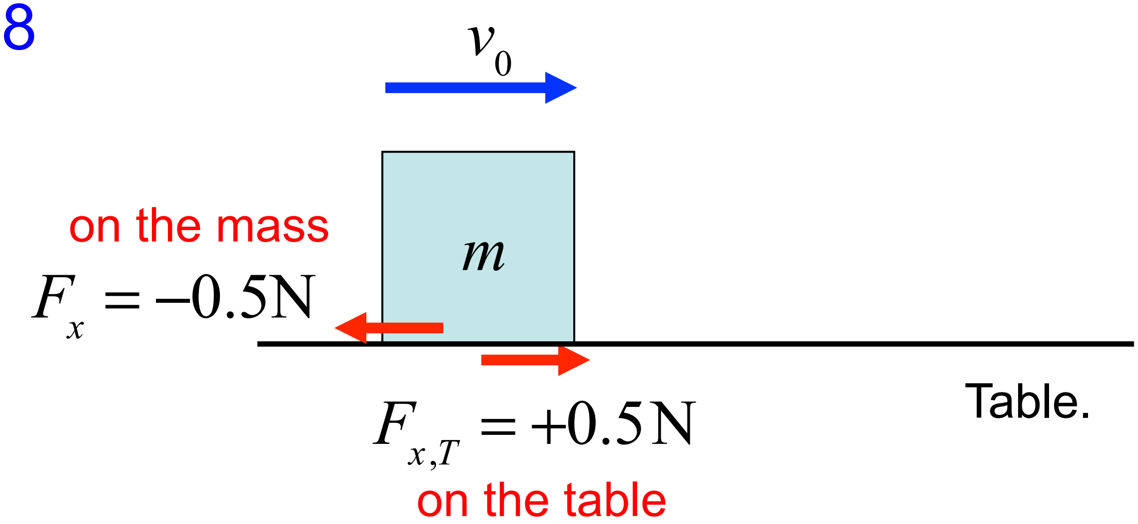

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b) $F_{x,T} = -0.5\,\text{N}$

c) $F_{x,T} = 0\,\text{N}$

d) $F_{x,T} = 60\,\text{N}$

e) A mass cannot make a force.

Bat hitting a baseball

Newton's 3^{rd} 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 3^{rd} 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?

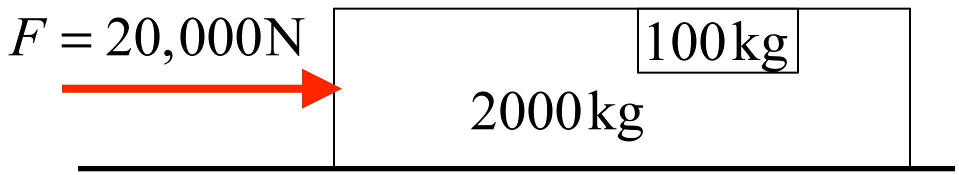
a) $200\,\text{N}$

b) $2000\,\text{N}$

c) $9.5\,\text{N}$

d) $100\,\text{N}$

e) $950\,\text{N}$



Acceleration is the same for car and driver

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

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

Example Multiple Choice 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?

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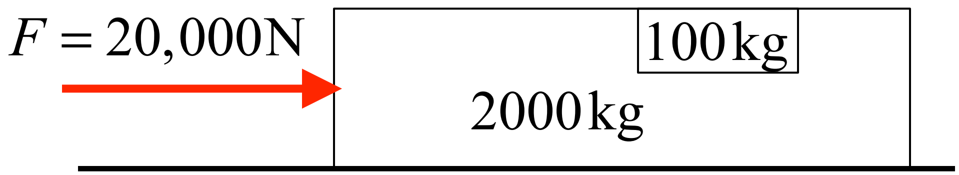

Acceleration is the same for car and driver

Use $\vec{\mathbf{F}} = m\vec{\mathbf{a}}$ (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 -

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

Clicker Question 4.9

A 10,000 kg garbage truck and a 1000 kg Chevy Volt collide. At the point of collision, consider the *magnitude* of the forces acting, and decide which statement below is true.

The force magnitude is always

a) ... larger on the smaller mass.

b) ... larger on the larger mass.

c) ... larger on the vehicle with highest speed.

d) ... larger on the vehicle with smallest speed.

e) ... the same on the two vehicles.

Clicker Question 4.9

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c) ... larger on the vehicle with highest speed.

d) ... larger on the vehicle with smallest speed.

e) ... the same on the two vehicles.

Newton's 3rd law!

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?

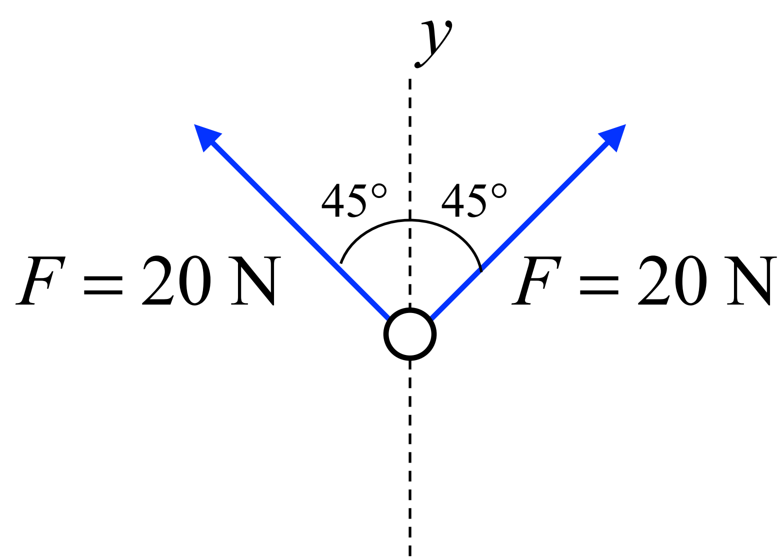
a) -40 N

b) -14 N

c) -32 N

d) -18 N

e) -28 N



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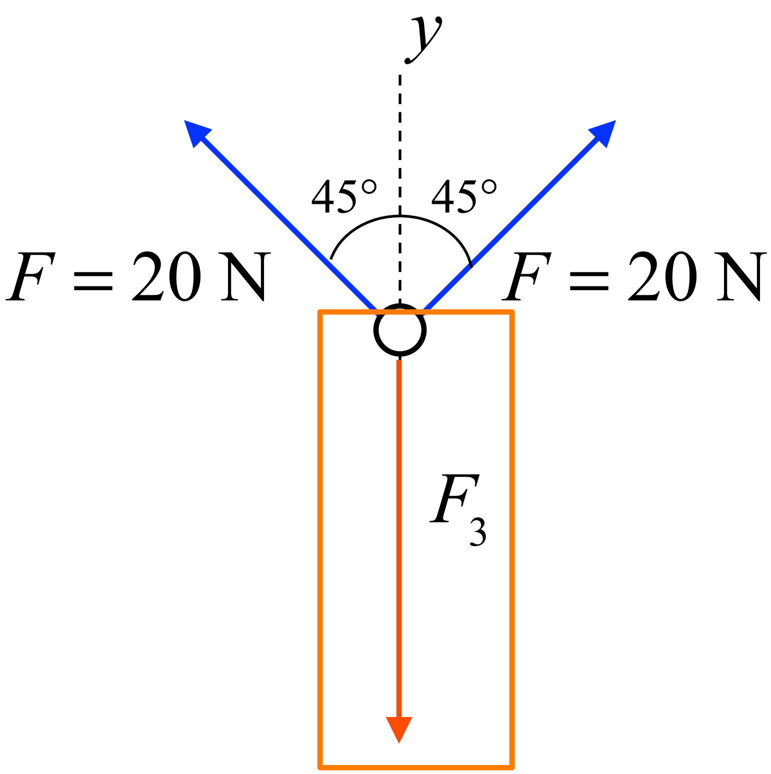


Example:

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?

Find y-component of each force

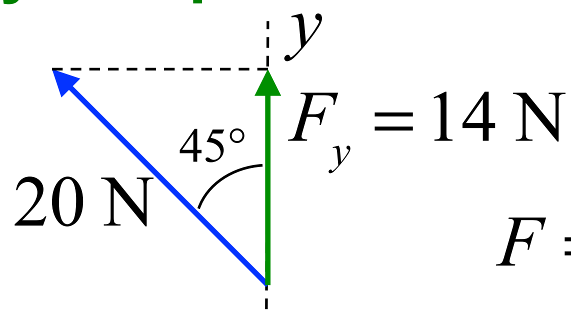
a) $-40\ \mathrm{N}$

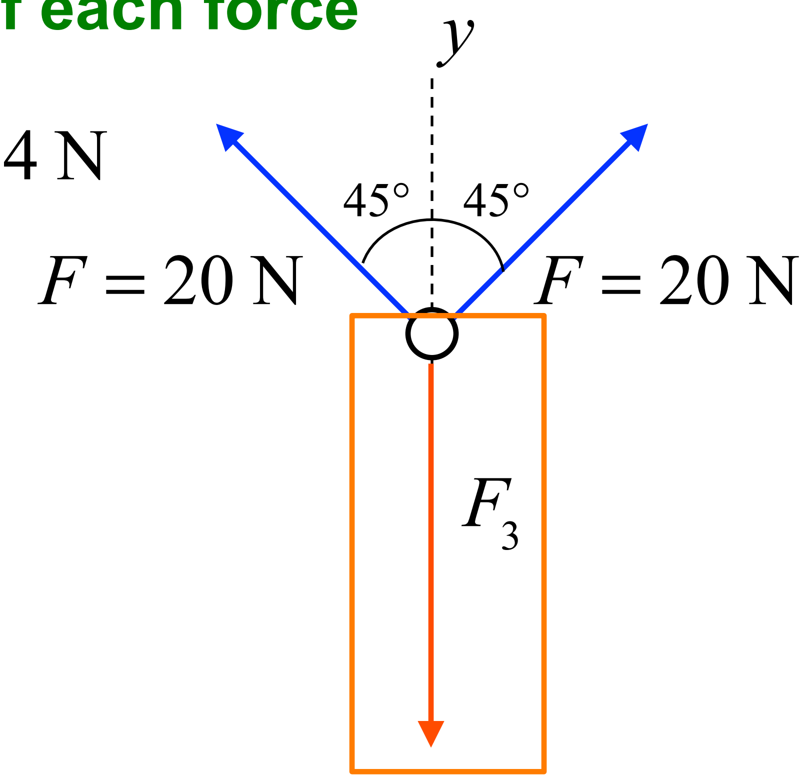
b) $-14\ \mathrm{N}$

c) $-32\ \mathrm{N}$

d) $-18\ \mathrm{N}$

e) $-28\ \mathrm{N}$





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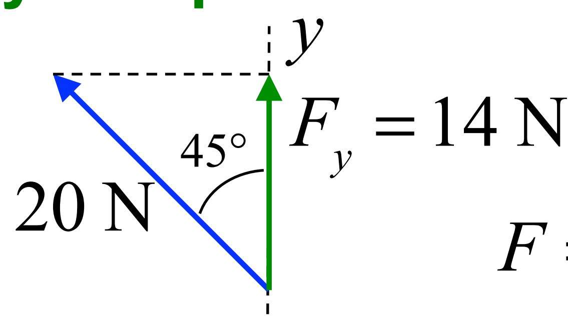
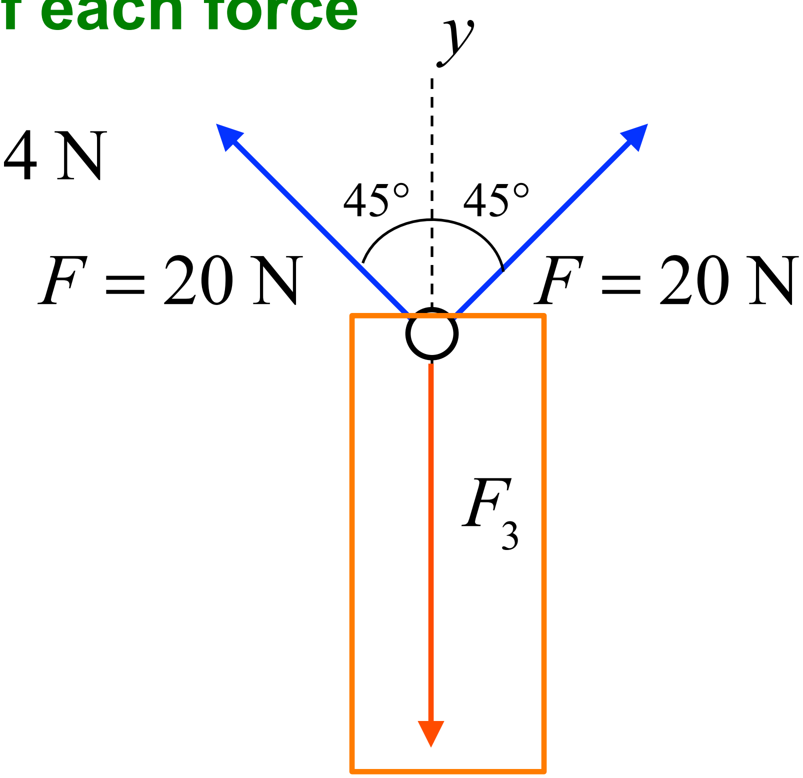




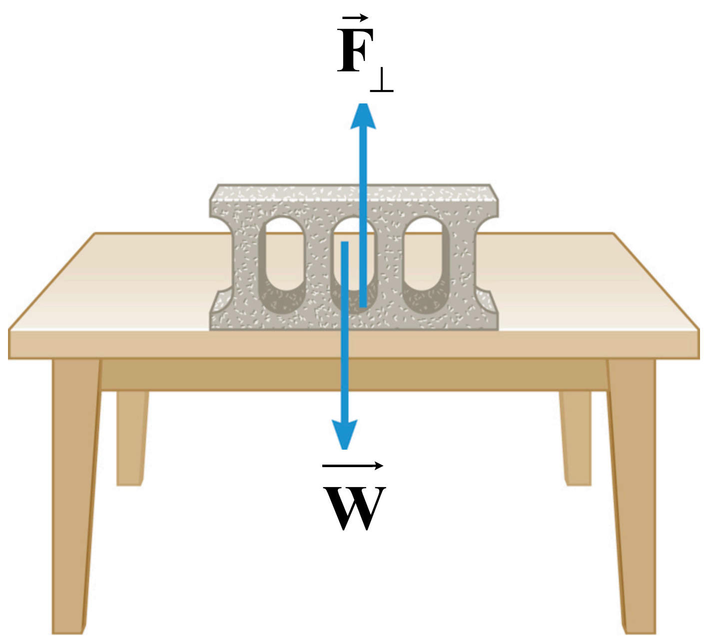
$$y: F_{Net} = 0 = 2\left(F\cos 45^\circ\right) + F_3$$

$$F_3 = -2\left(F\cos 45^\circ\right) = -28\,\mathrm{N}$$

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 $\vec{\mathbf{n}}$



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.

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

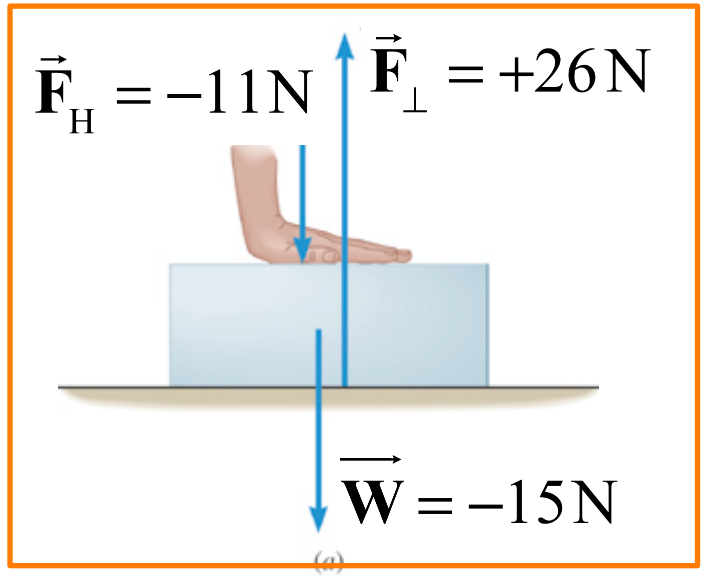
three forces act on block

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

$$\vec{F}_{\perp} = -\vec{F}_{\text{H}} - \overrightarrow{W}$$

$$= -\left(-11\text{N}\right) - \left(-15\text{N}\right)$$

$$= +26 \text{ N}$$

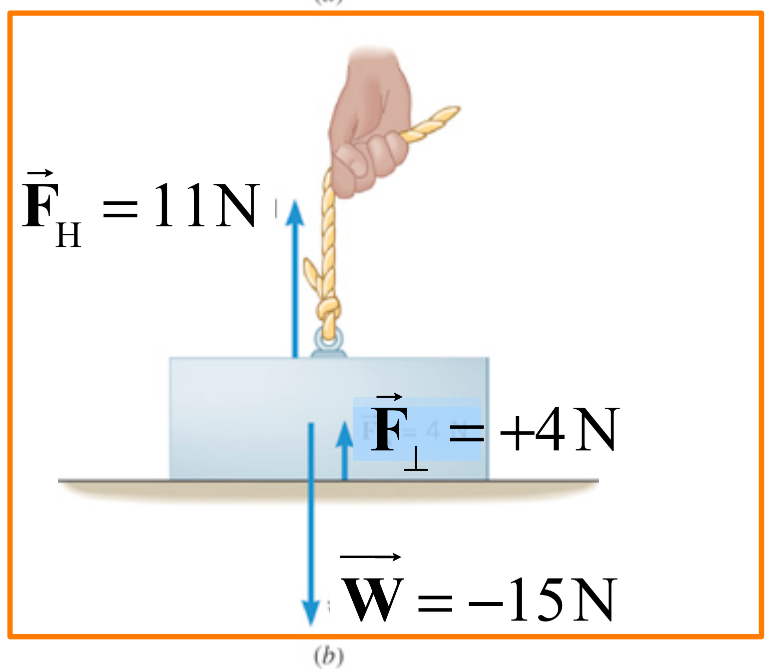


$$\vec{F}_{\text{Net}} = \vec{F}_{\perp} + \vec{F}_{H} + \overrightarrow{W} = 0$$

$$\vec{F}_{\perp} = -\vec{F}_{H} - \overrightarrow{W}$$

$$= -(11\text{N}) - \left(-15\text{N}\right)$$

$$= +4\text{N}$$



4.3 Newton’s Laws of Motion (Elevators)

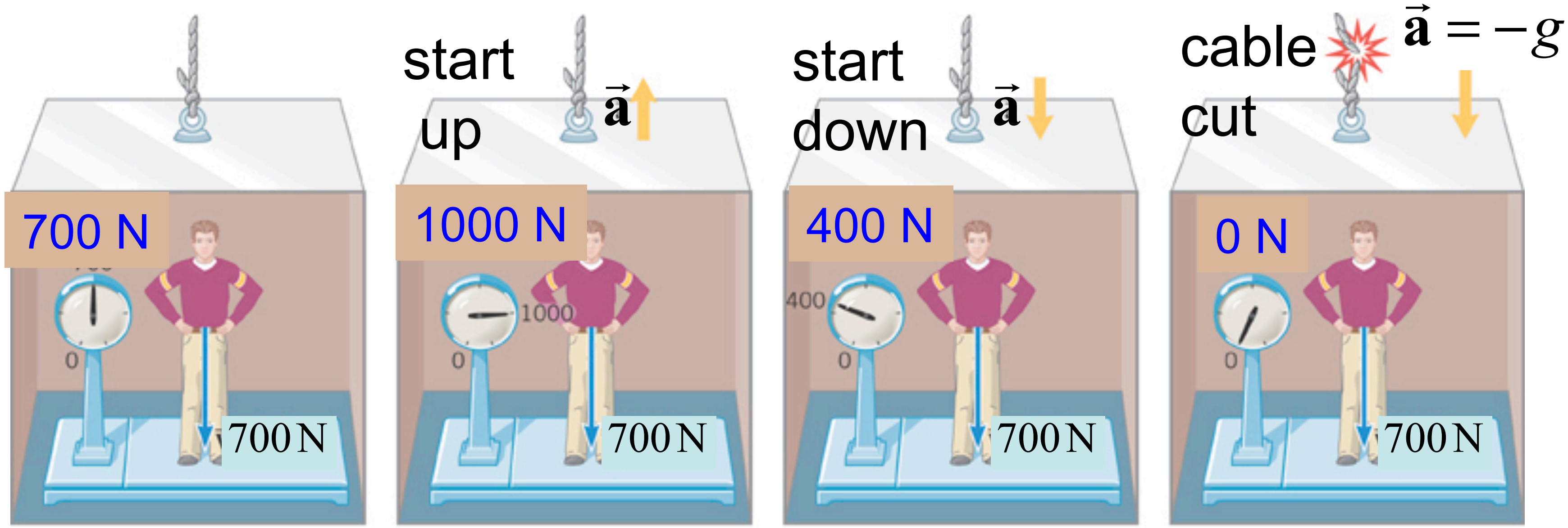
<u>*Apparent Weight = Normal force acting on an object*</u>

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

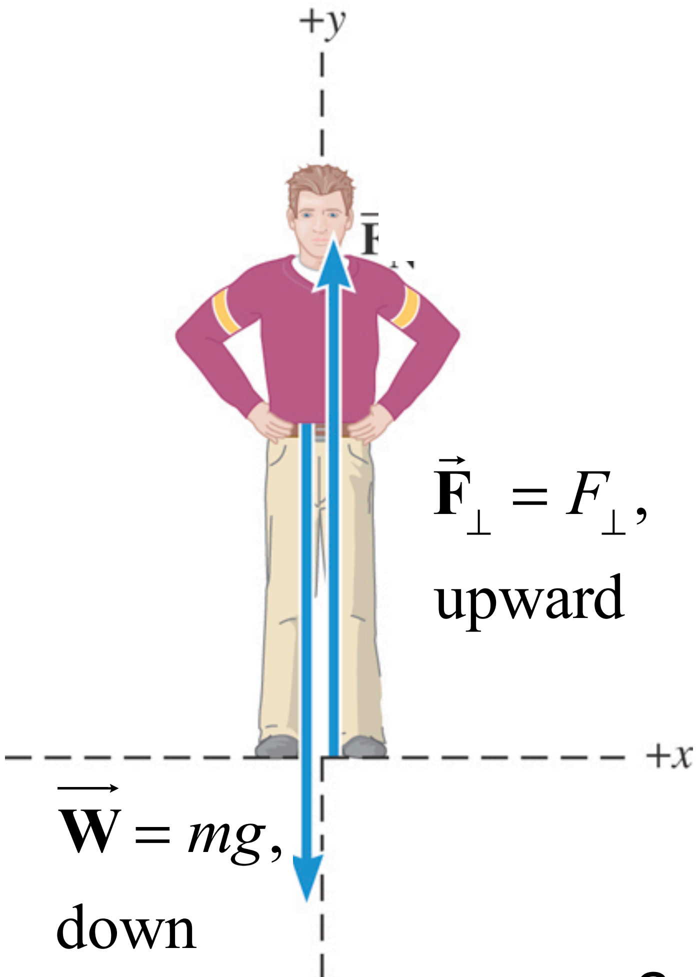
accelerating a, upward

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

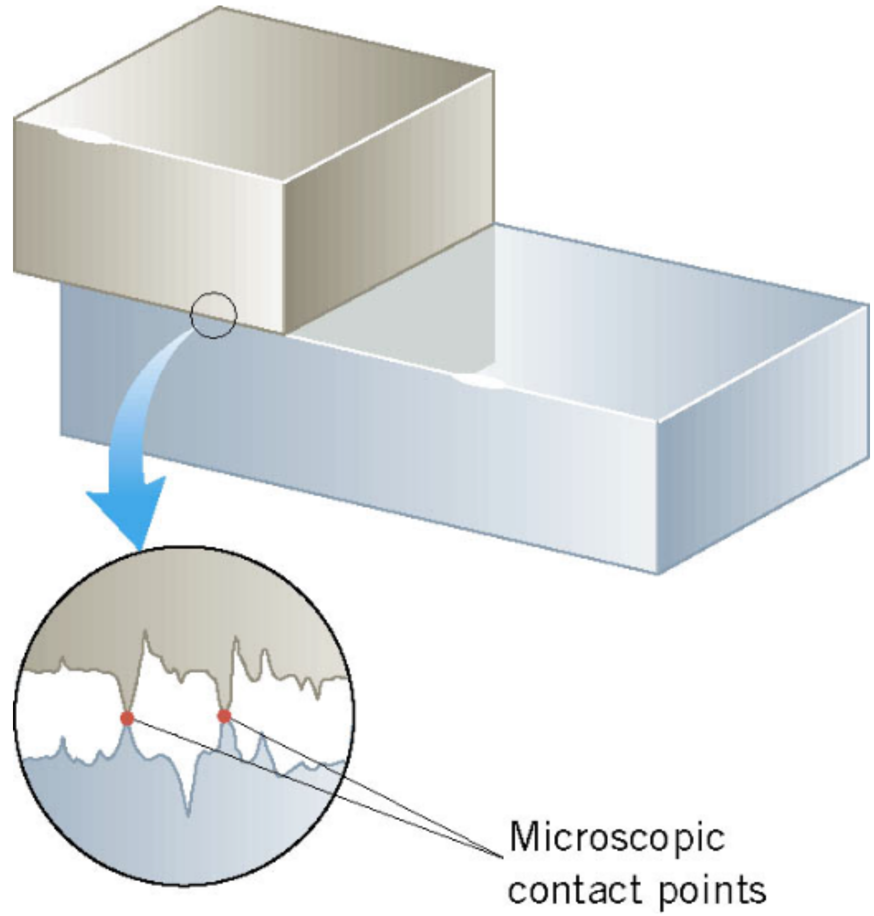
a_y is up: apparent weight > true weight

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

$\vec{\mathbf{F}}_{\mathrm{R}}$ = rope force

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

No movement

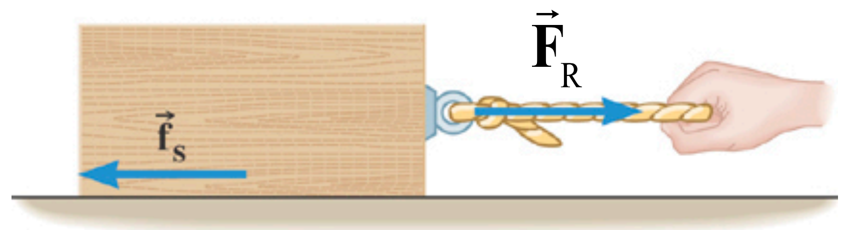
$\vec{\mathbf{f}}_S$ = static friction force

Block is at rest. Net force is zero on block

$$\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_{\mathrm{R}} + \vec{\mathbf{f}}_S = 0$$

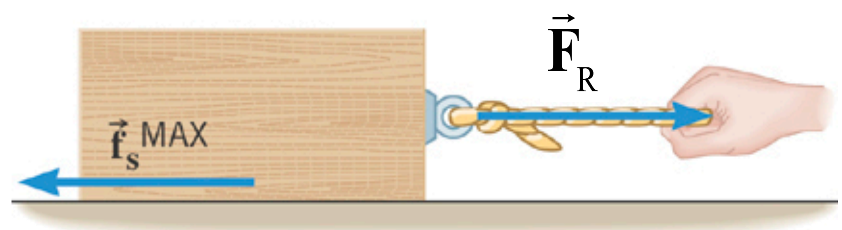
$$+F_{\mathrm{R}} + (-f_S) = 0 \text{ (opposite } x \text{ directions)}$$

$$F_{\mathrm{R}} = f_S \text{ (same magnitude)}$$



No movement
(*b*)

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

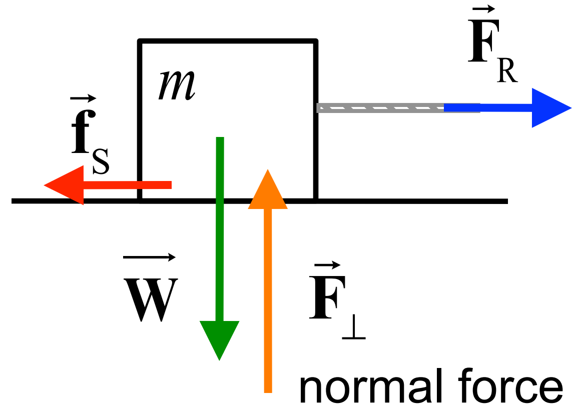


When movement just begins
(*c*)

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

4.4 ***Static and Kinetic Frictional Forces***

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



normal force of table on the mass

Friction equations are for MAGNITUDES only.

$$f_{\mathrm{S}} \le f_{\mathrm{S}}^{\mathrm{Max}} \quad \text{(object remains at rest)}$$

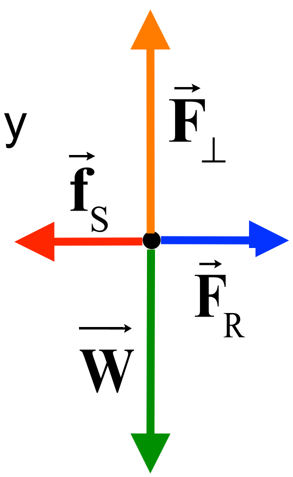
$$f_{\mathrm{S}}^{\mathrm{MaX}} = \mu_{\mathrm{S}} F_{\perp},$$

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

Vertical forces only

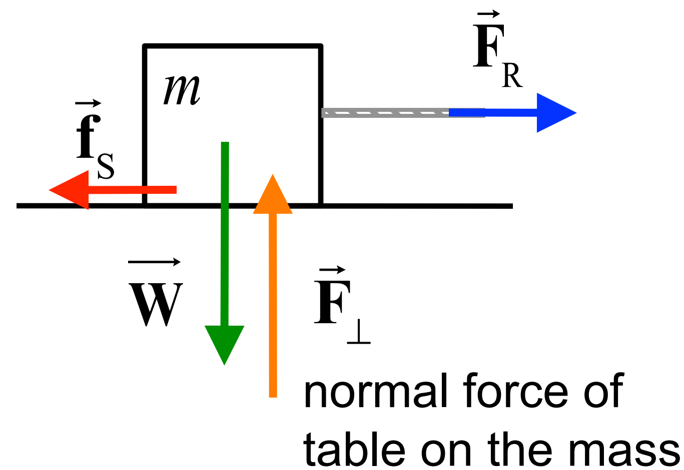
$$F_{\perp} = W = mg$$

Free body diagram



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?

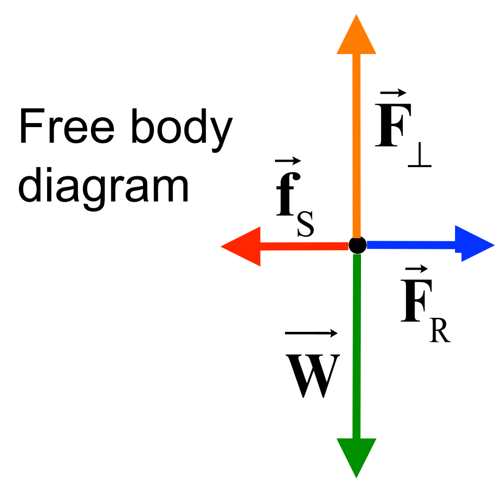


$$W = mg = 49{,}000\text{N (magnitude)}$$

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

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

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



Clicker Question 4.10

$$f_{\mathrm{S}}^{\mathrm{MaX}} = \mu_{\mathrm{S}} F_{\perp}$$

A 50.0 kg mass is at rest on a table, where the coefficient of friction, $\mu_{\mathrm{S}} = 0.50$. 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

A 50.0 kg mass is at rest on a table, where the coefficient of friction, $\mu_S = 0.50$. What is the lowest horizontal force that will get the mass to begin to move?

a) 25 N

b) 49 N

$\boxed{\text{c) 245 N}}$

d) 490 N

e) 980 N

$$\boxed{\begin{aligned} f_S^{\text{Max}} &= \mu_S F_\perp = \mu_S W \\ &= 0.50(mg) = 0.50(50.0\,\text{kg})(9.81\ \text{m/s}^2) \\ &= 245\ \text{N} \end{aligned}}$$

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.

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

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

OK because friction equations are for MAGNITUDES only.

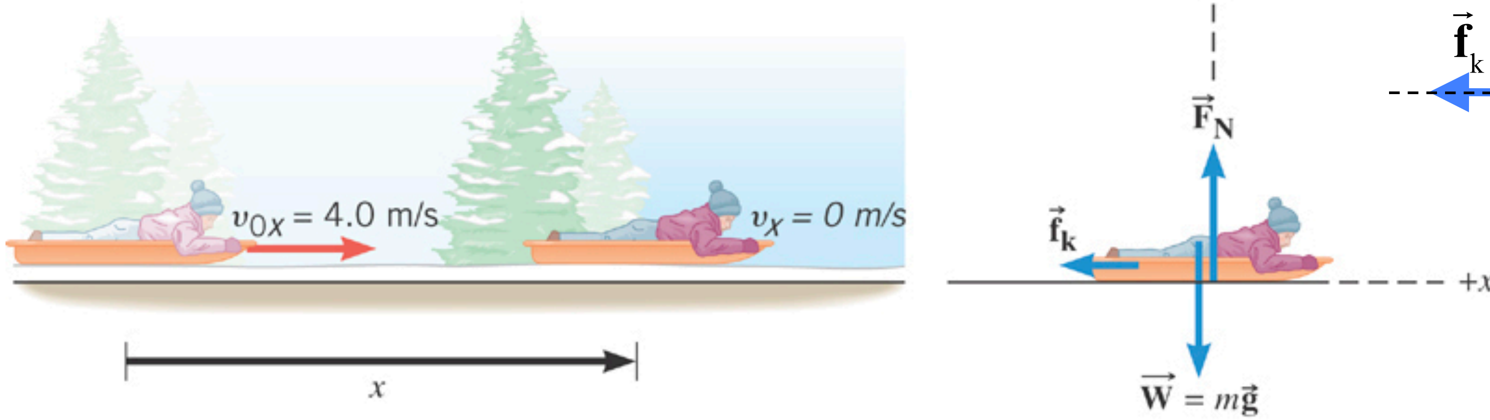
4.4 Static and Kinetic Frictional Forces

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.

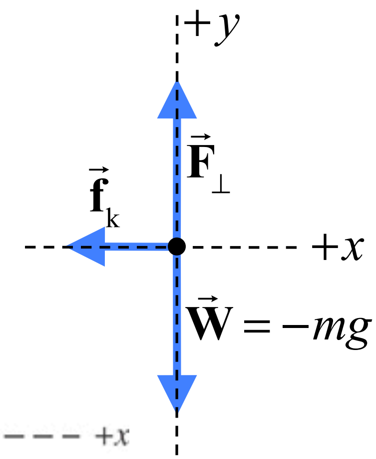
4.4 Static and Kinetic Frictional Forces



(a)

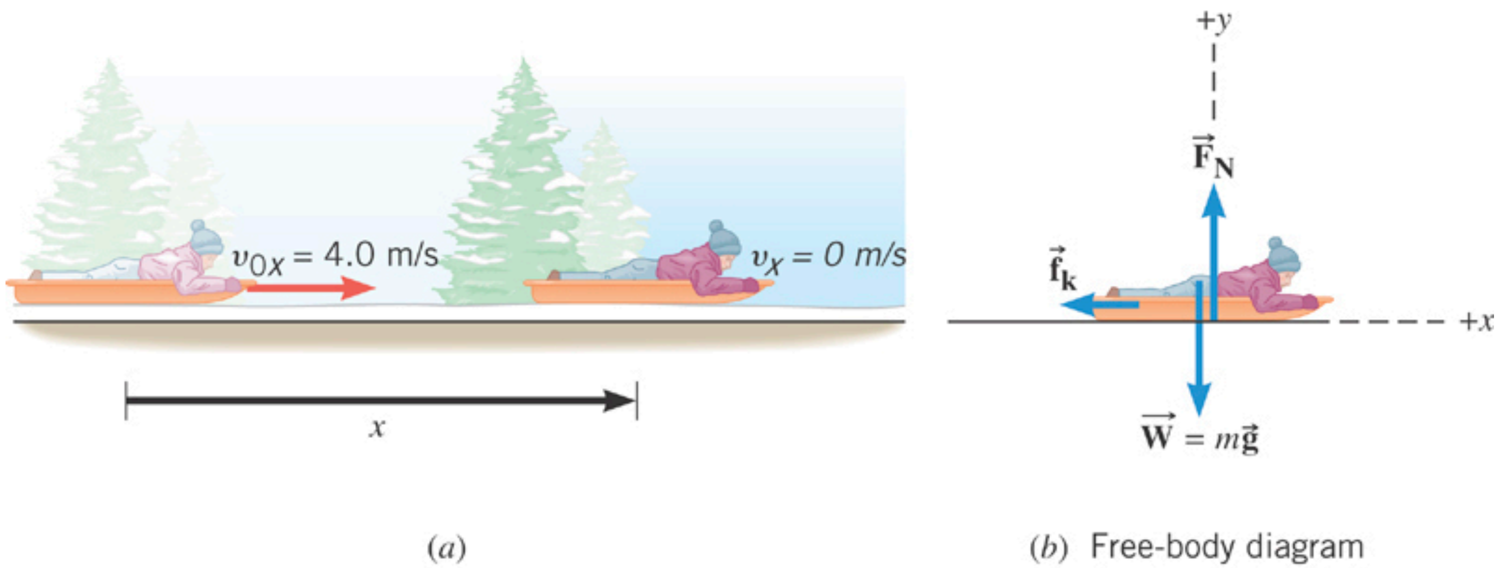
(b) Free-body diagram for the sled and rider

Free Body Diagram



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

4.4 Static and Kinetic Frictional Forces



(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?

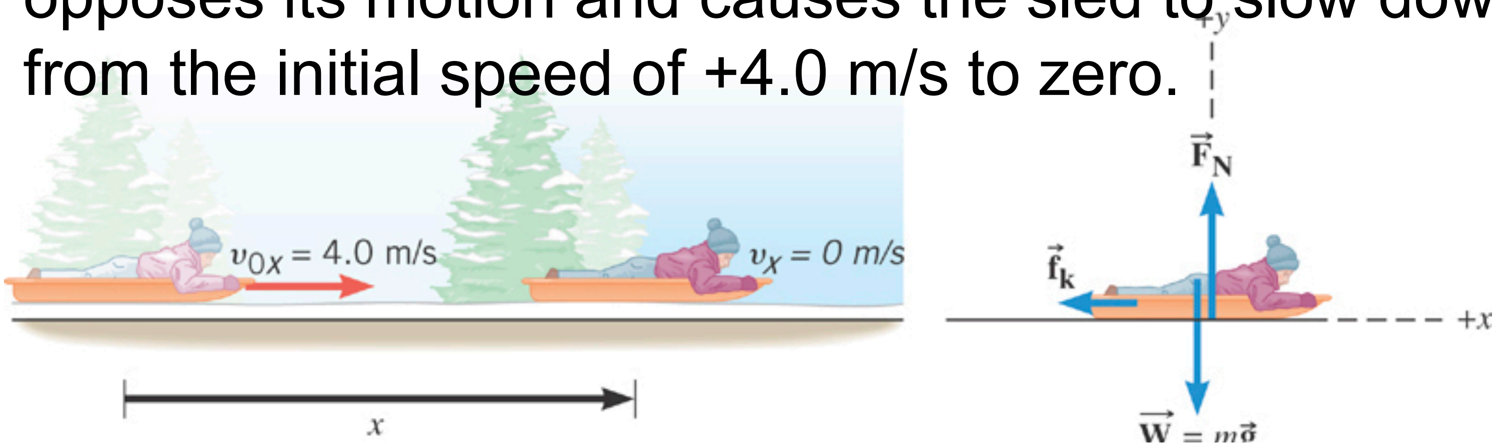
$$f_k = \mu_k F_N$$

Friction equations are for MAGNITUDES only.

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

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 from the initial speed of +4.0 m/s to zero.



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

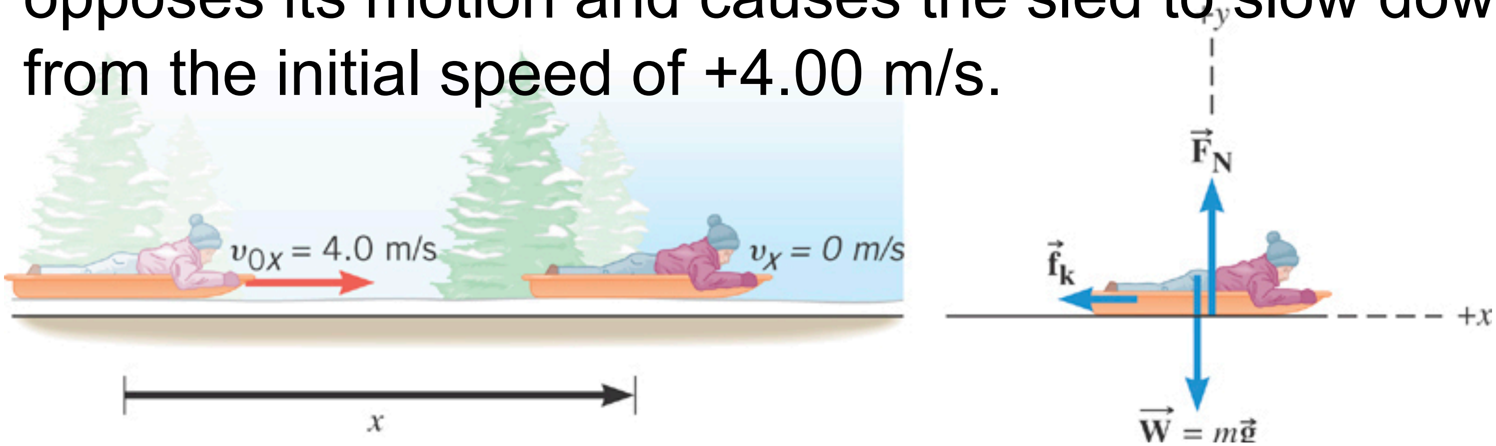
Hints

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 +4.00 m/s.



If the magnitude of the kinetic frictional force, $f_k = 20.0\text{N}$, and the total mass is 40.0kg, how far does the sled travel?

a) 2m

b) 4m

c) 8m

d) 16m

e) 32m

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

$$a = \frac{f_k}{m} = \frac{-20.0\,\text{N}}{40.0\,\text{kg}} = -0.50\ \text{m/s}^2$$

$$\boxed{x = \frac{-v_{0x}^2}{2a} = \frac{-16.0\,\text{m}^2/\text{s}^2}{2(-0.50\ \text{m/s}^2)} = +16.0\,\text{m}}$$

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

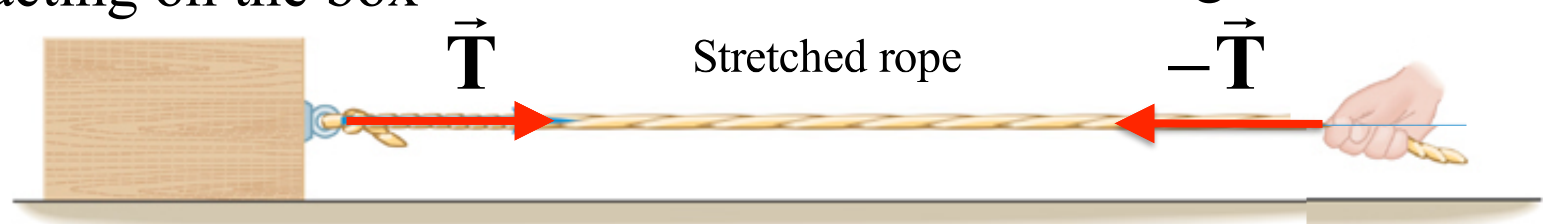
Box surface force acting on the rope

Hand force acting on the rope

(*b*)

Rope tension force acting on the box

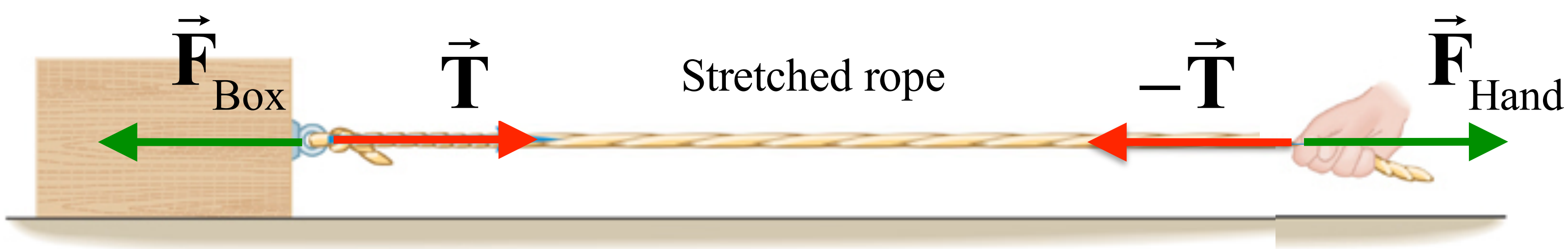
Rope tension force acting on the hand



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

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

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

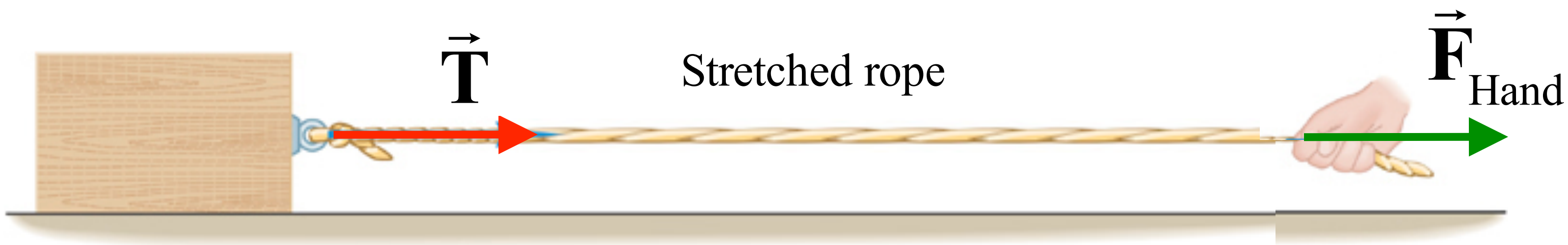
Box pulls on rope

Tension pulls on hand

Hand pulls on rope

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

These are the important forces

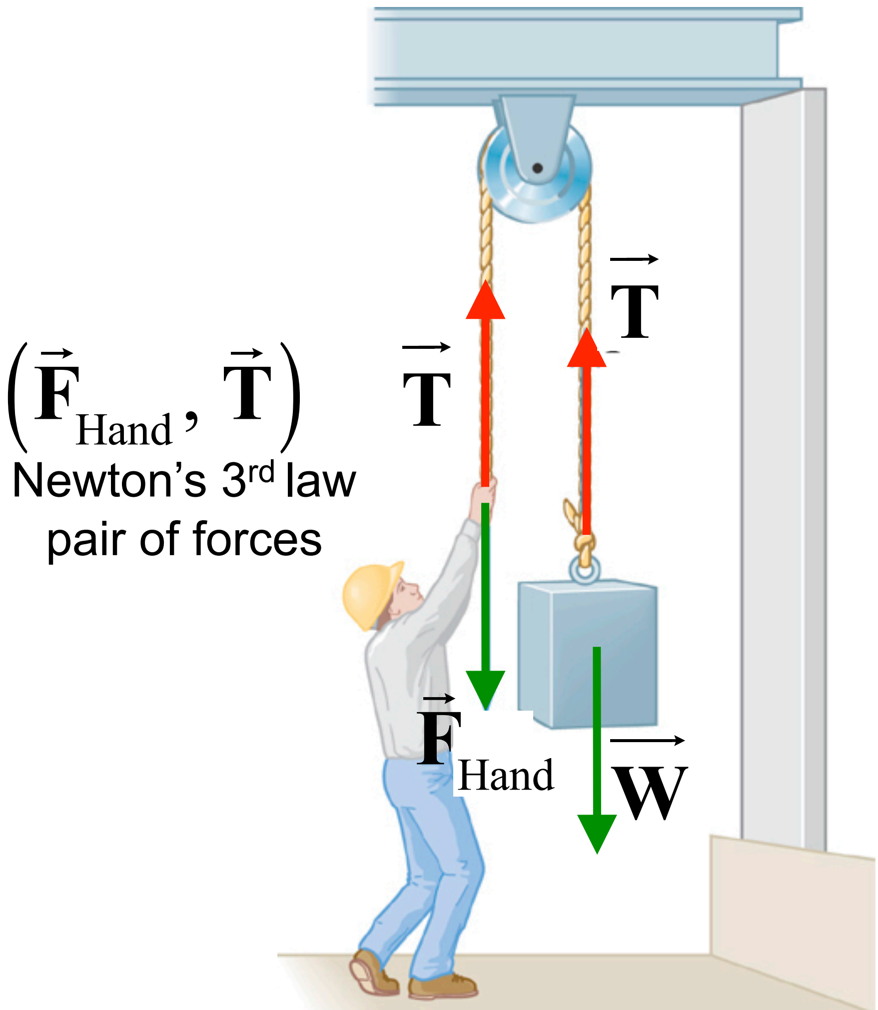


Hand force causes a tension force on the box

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!

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

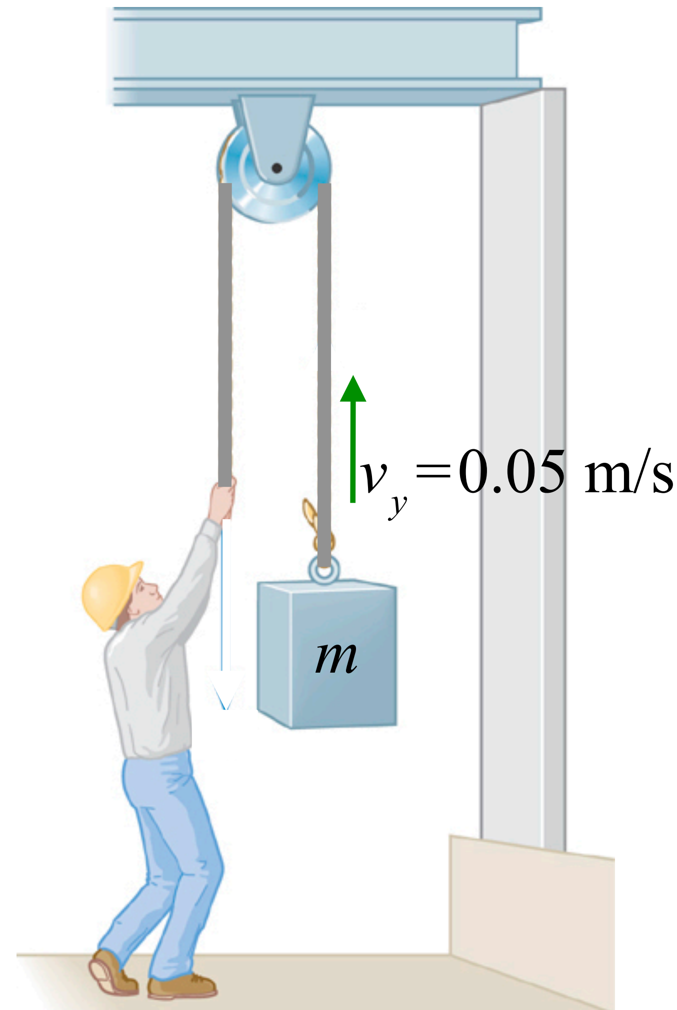
$$0 = -mg + \vec{\mathbf{T}}$$

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

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

Clicker Question 4.14

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

Clicker Question 4.14

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 upward speed of the mass.

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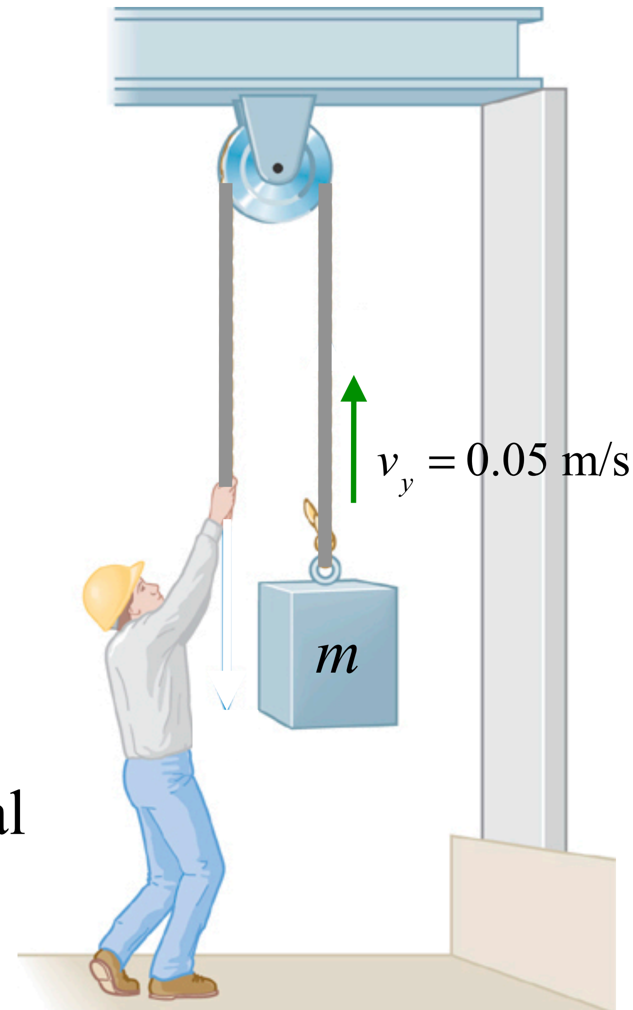


Constant speed and direction $\Leftrightarrow$ no net force.

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

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

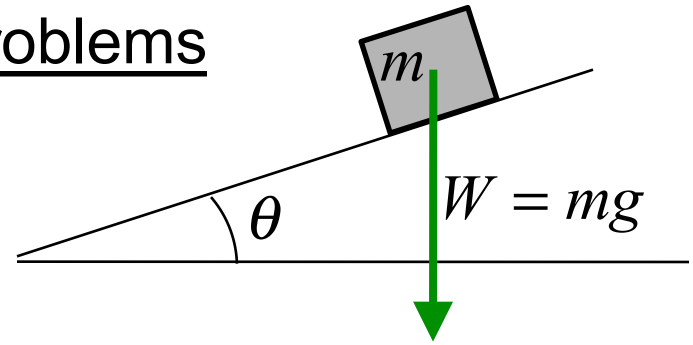
- Select an object(s) to which the equations of equilibrium are to be applied.

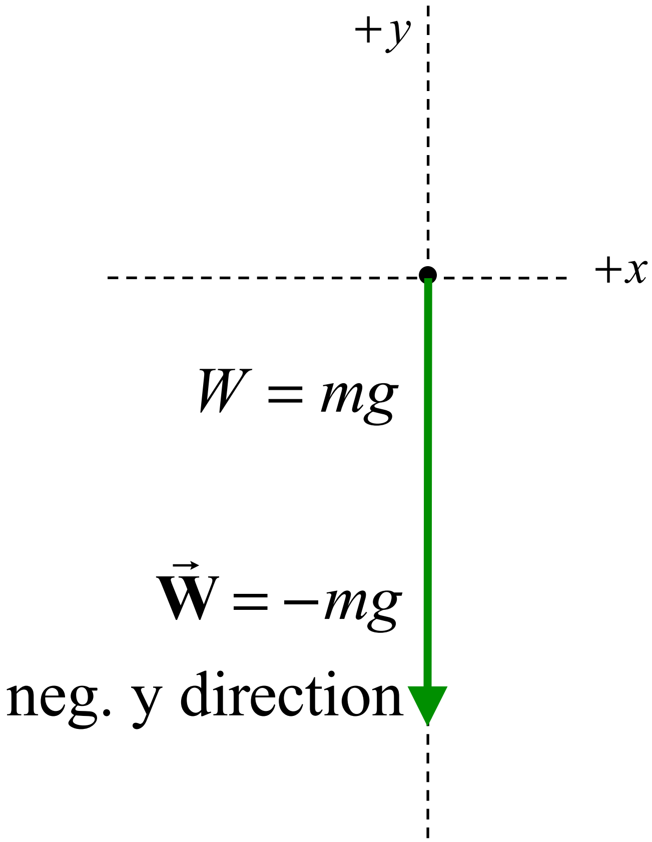
- Draw a free-body diagram for each object chosen above. Include only forces acting on the object, not forces the object exerts on its environment.

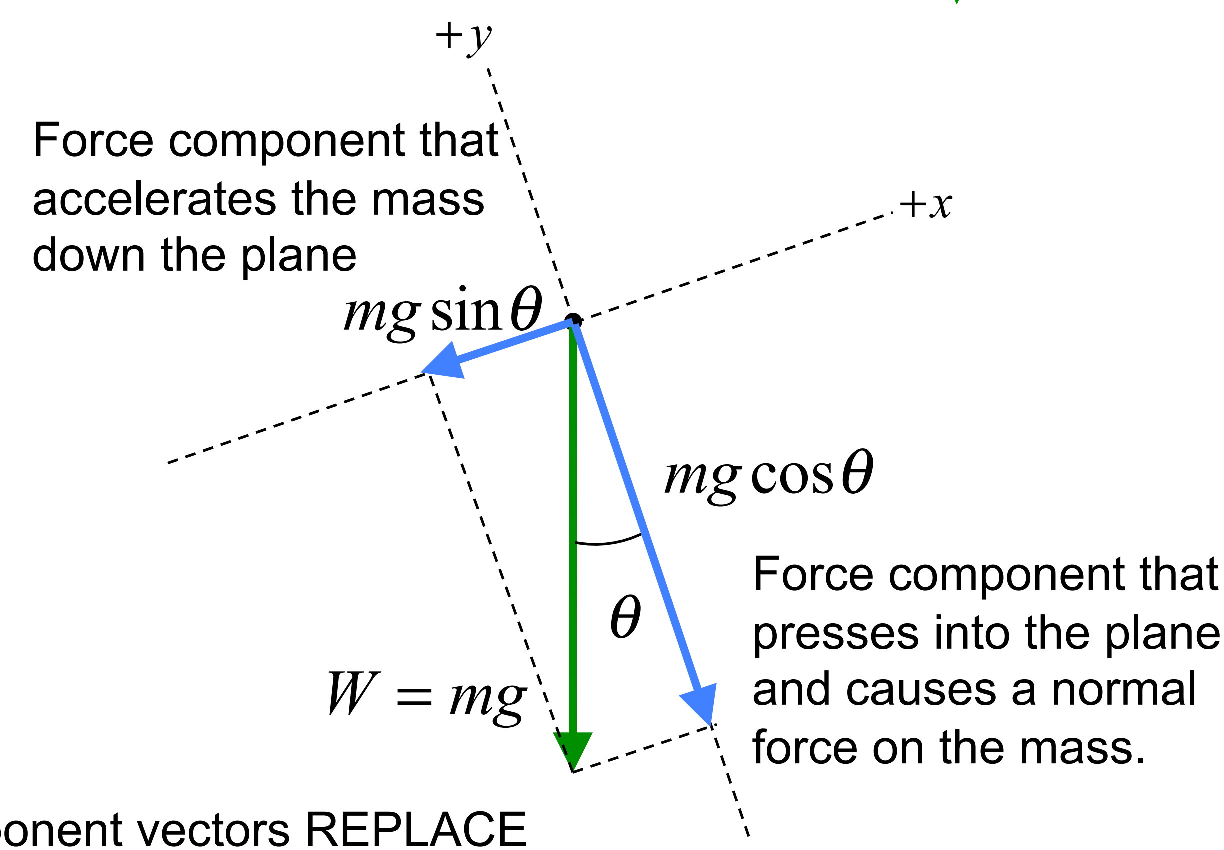
- Choose a set of *x*, *y* axes for each object and resolve all forces in the free-body diagram into components that point along these axes.

- Apply the equations and solve for the unknown quantities.

Inclined plane and similar problems







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