Chapter 4

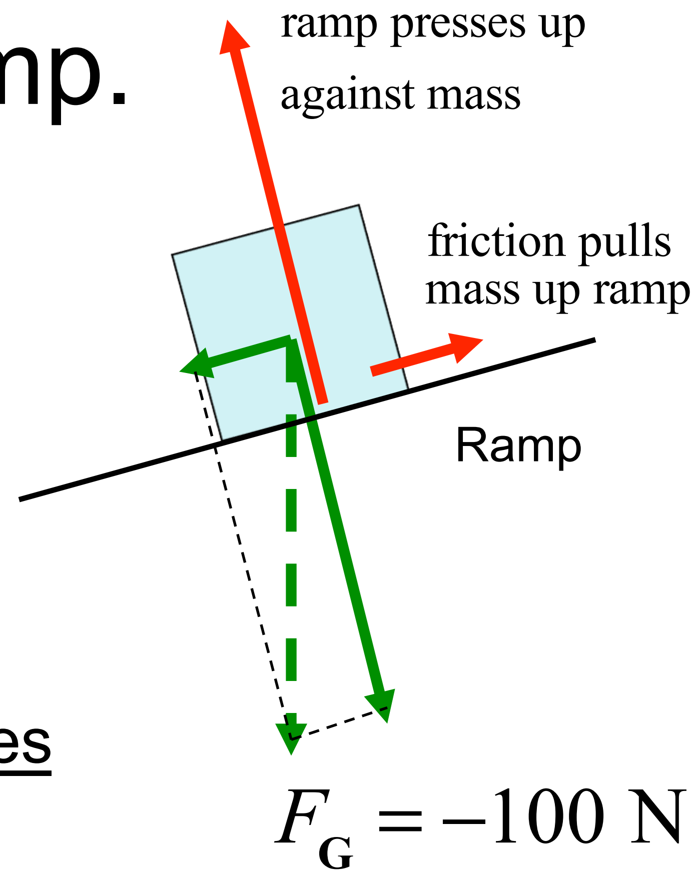
Forces and Newton's Laws of Motion

continued

Clicker Question 4.3

A mass at rest on a ramp.

How does the friction between the mass and the table "know" how much force will EXACTLY balance the gravity force pulling the mass down the ramp?



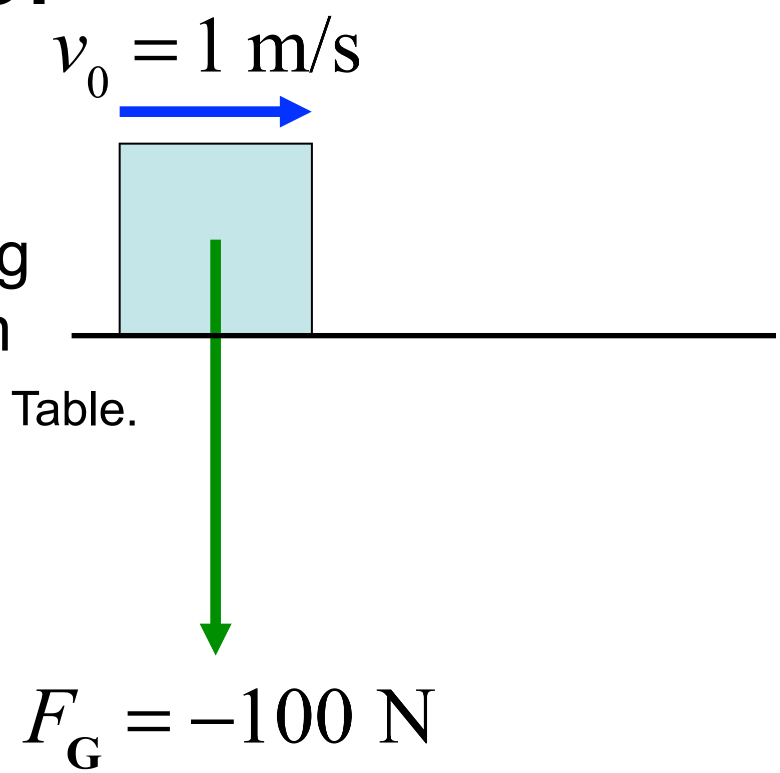
As you slowly put the mass on the ramp, the ramp compresses & stretches along the ramp as gravity *tries* to slide the mass down the ramp. When you let go, the ramp has stretched enough to push on the mass with EXACTLY the right amount of force up the ramp.

At rest: Net force must be zero

Clicker Question 4.4

Mass sliding on a table.

Gravity applies a force to a mass.
It is sliding on a table with an initial velocity of +1 m/s. It slows while sliding to +0.5 m/s. The friction between them applies a force in what direction?



a) Upward

b) Downward

c) To the right (+)

d) To the left (–)

e) A table can't make a force.

Newton's Second Law

When a net external force acts on an object of mass *m*, the acceleration that results is directly proportional to the net force and has a magnitude that is inversely proportional to the mass. The direction of the acceleration is the same as the direction of the net force.

$$\vec{\mathbf{a}} = \frac{\sum \vec{\mathbf{F}}}{m}$$

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

Sum of forces acting on 1 object

SI Unit for Force

$$(\text{kg})\left(\frac{\text{m}}{\text{s}^2}\right) = \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$

Note: it has the same units as ma.

This combination of units is called a *newton* (N).

$$1\,\text{kg}\cdot\text{m/s}^2 = 1\,\text{N}$$

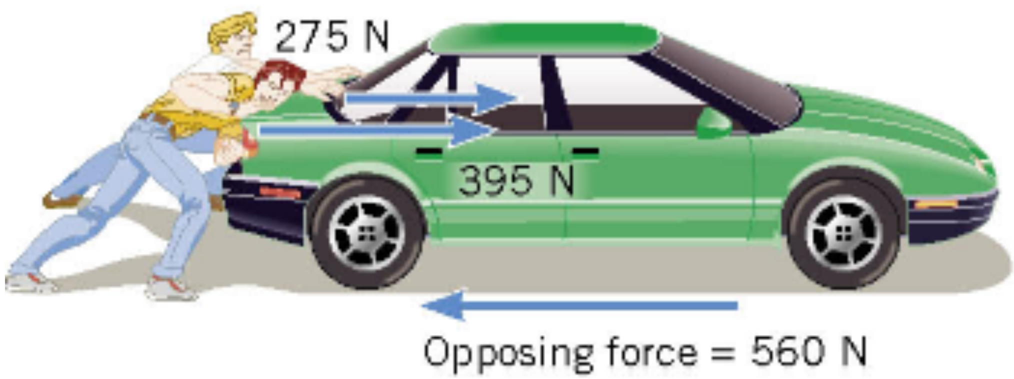
4.2 Newton's Laws of Motion (Second Law)

Table 4.1 Units for Mass, Acceleration, and Force

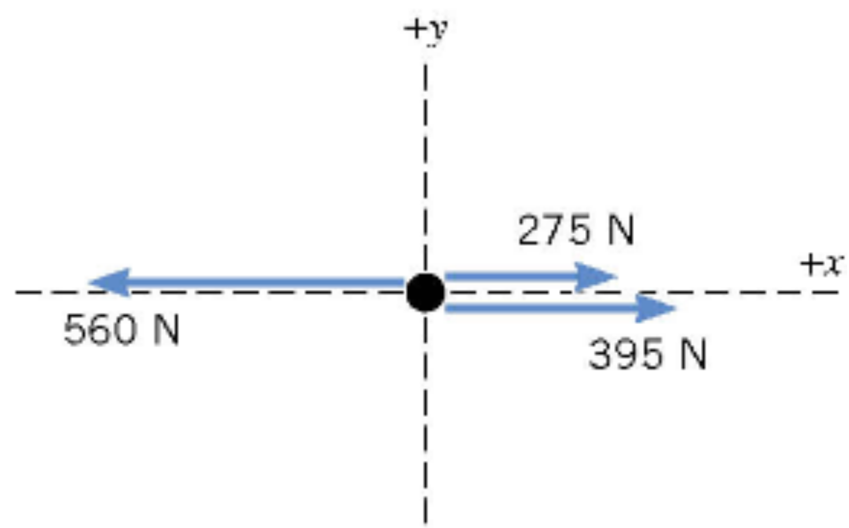
System	Mass	Acceleration	Force
SI	kilogram (kg)	meter/second^2 (m/s^2)	newton (N)
CGS	gram (g)	centimeter/second^2 (cm/s^2)	dyne (dyn)
BE	slug (sl)	foot/second^2 (ft/s^2)	pound (lb)

$\sim 5\,\text{N} = 1\,\text{lb}$

A ***free-body-diagram*** is a diagram that represents the object and the forces that act on it.

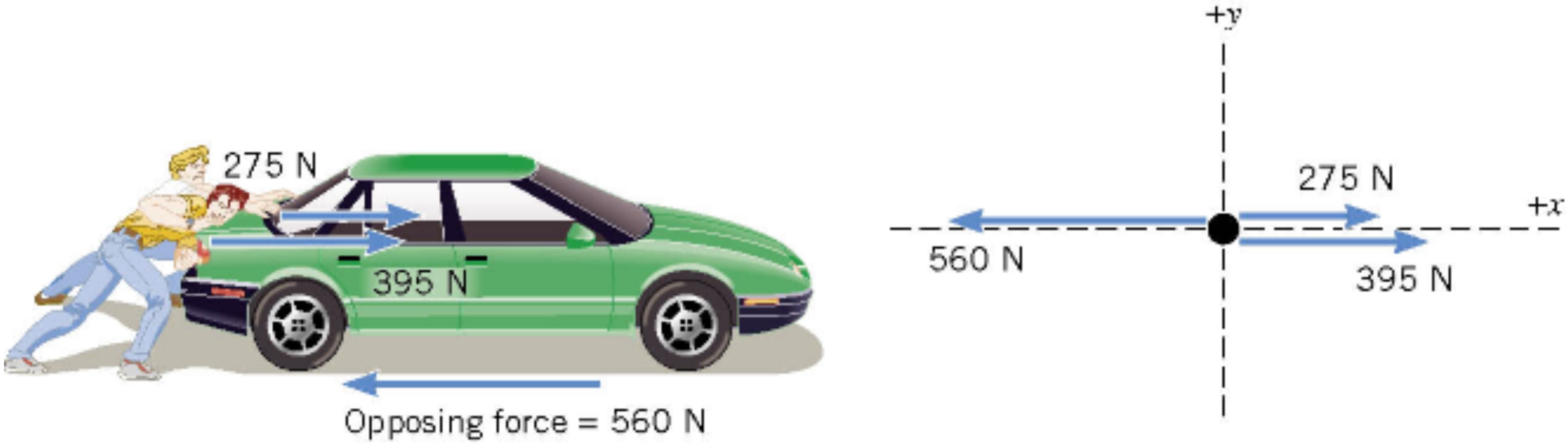


(a)



(b) Free-body diagram of the car

4.2 Newton's Laws of Motion (Second Law)



(a)

(b) Free-body diagram of the car

The net force in this case is:

275 N + 395 N – 560 N = +110 N

and is directed along the + x axis of the coordinate system.

If the mass of the car is 1850 kg then, by Newton's second law, the acceleration is

$$a = \frac{\sum F}{m} = \frac{+110\,\mathrm{N}}{1850\,\mathrm{kg}} = +0.059\,\mathrm{m/s^2}$$

Clicker Question 4.5

With the acceleration just calculated $a = 0.059 \text{ m/s}^2$ and starting at rest, how far has the car gone after 10 s of pushing?

a) 0.059 m

b) 10 m

c) 0.59 m

d) 3.0 m

e) 0.3 m

The direction of force and acceleration vectors can be taken into account by using *x* and *y* components.

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

is equivalent to

$$\sum F_x = ma_x \quad \& \quad \sum F_y = ma_y$$

Net Force in x-direction = *m* times *a* in x-direction

AND

Net Force in y-direction = *m* times *a* in y-direction

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

How to use Newton's 2nd law, $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ one object

A) If mass of the object is known, *and* all forces acting on the object are known, then the acceleration vector can be calculated.

B) If the acceleration vector and mass of an object are known, then the Net Force acting on the object can be calculated. It may surprise you!

C) If the acceleration vector and mass of an object are known, but the calculated Net Force and the identified forces disagree, at least one additional force must act on the object. Find it!

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

A) If mass of the object is known, *and* all forces acting on the object are known, then the acceleration vector can be calculated.

⇓

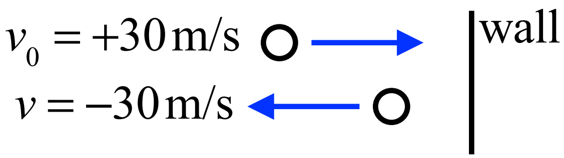
Once the Net Force acting on an object and Newton's 2nd law are used to calculate the object's acceleration vector, future changes of the position and velocity can be predicted.

$$a_x = \frac{\sum F_x}{m} \qquad a_y = \frac{\sum F_y}{m}$$

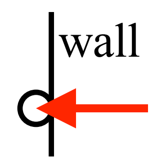
one object

B) If the acceleration vector and mass of an object are known, then the Net Force acting on the object can be calculated.

A paddle ball travelling horizontally bounces off a wall. The *speed* of the ball was 30 m/s before and after hitting the wall. If contact with the wall was for 0.02 s, what was the ball's acceleration during the contact?



If the paddle ball has a mass of 0.2 kg, what is the force that the wall applied to the ball?



$F = ?$

one object

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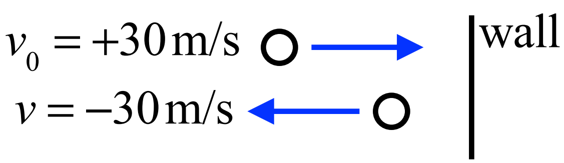
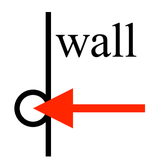


$$a = \frac{(v - v_0)}{t} = \frac{[-30 - (+30)]\,\text{m/s}}{.02\text{ s}} = -3000\text{ m/s}^2$$

If the paddle ball has a mass of 0.2 kg, what is the force that the wall applied to the ball?



$$F = ?$$

one object

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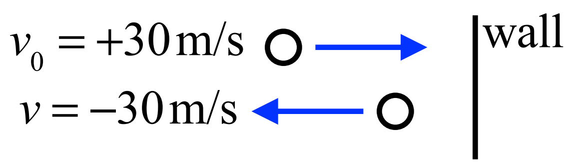
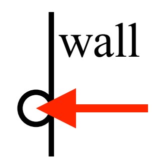


$$a = \frac{(v - v_0)}{t} = \frac{[-30 - (+30)]\,\text{m/s}}{.02\ \text{s}} = -3000\ \text{m/s}^2$$

If the paddle ball has a mass of 0.2 kg, what is the force that the wall applied to the ball?

$$F_x = ma_x$$
$$= (0.2\ \text{kg})(-3000\ \text{m/s}^2)$$
$$= -600\ \text{kg-m/s}^2 \text{ or } -600\ \text{N}$$



$F = -600\,\text{N}$

Force on ball is to the LEFT

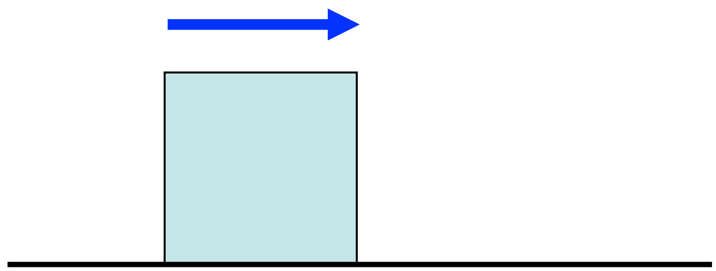
Magnitude of 600 N

(~120 lbs)

C) If the acceleration vector and mass of an object are known, but the calculated Net Force and the identified forces disagree, at least one additional force must act on the object. Likely you will not know the origin of this force, but it must be there.

A mass sliding on a table.

$v_0 = +1 \text{ m/s}$



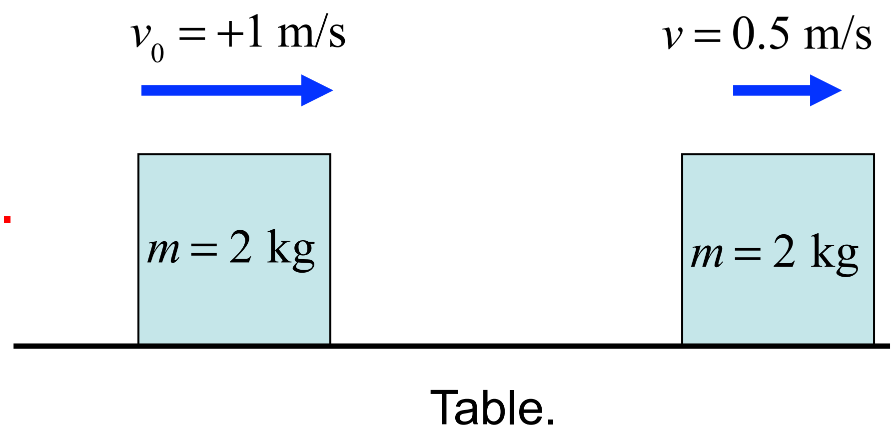
A 2 kg mass slides on a table with an initial velocity of +1 m/s. It slows while sliding to +0.5 m/s, in 2 seconds.

Table.

1) Calculate the acceleration vector
2) Use Newton's 2nd law, to calculate the frictional force that must act on the mass.

Clicker Question 4.6

A 2.0 kg mass sliding on a table with an initial velocity of +1.0 m/s, slows to +0.5 m/s, in 2.0 seconds.



A force acting on the mass causes it to lose speed. What is the magnitude and direction of this force?

a) $F = -0.5\,\text{N}$

b) $F = +0.5\,\text{N}$

c) $F = -1.0\,\text{N}$

d) $F = +1.0\,\text{N}$

e) $F = -2.0\,\text{N}$

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)

4.2 Newton's Laws of Motion (Weight)

Relation Between Mass and Weight

WEIGHT is a force vector

$$\vec{\mathbf{W}}$$

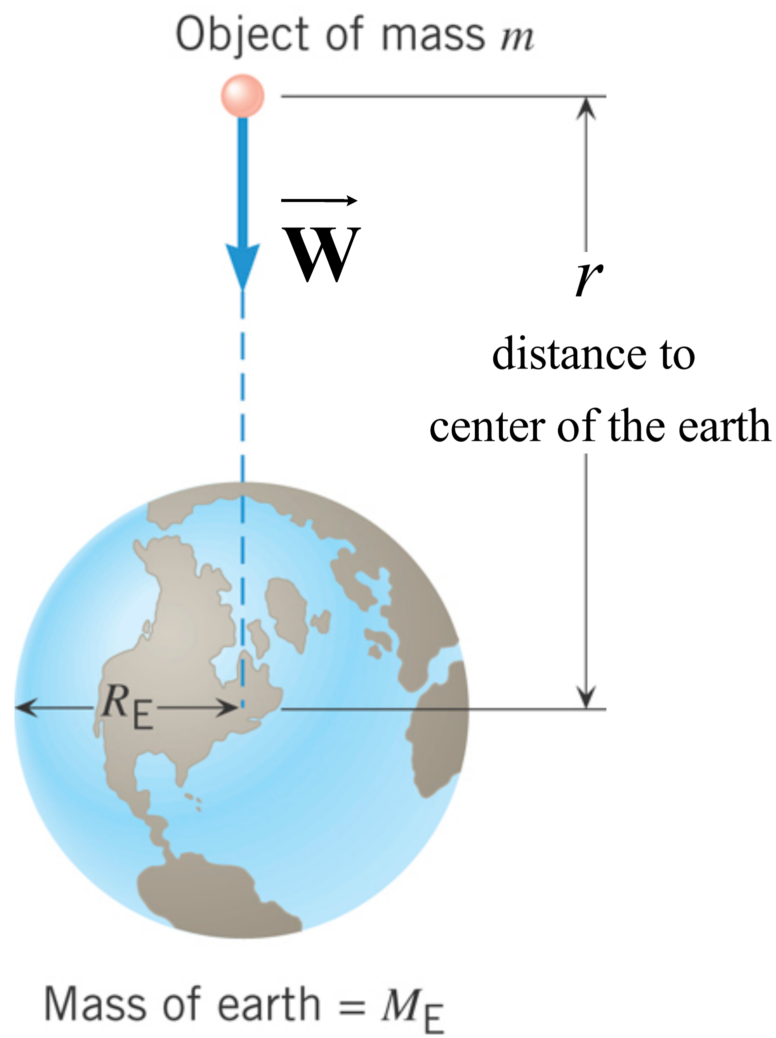
WEIGHT(magnitude) of the mass m

$$W = mg$$

Your WEIGHT

WEIGHT DEFINITION

Your "weight" is the force that gravity applies on your body.



Near the earth's surface

$$g = G\frac{M_E}{R_E^2}$$

$$r = R_E = 6.38\times10^6\ \text{m}$$

Radius of the earth

$$= \left(6.67\times10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2\right)\frac{\left(5.97\times10^{24}\ \text{kg}\right)}{\left(6.37\times10^6\ \text{m}\right)^2}$$

$$= 9.81\ \text{m/s}^2$$

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

Your WEIGHT on the earth

$$W = mg$$

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

$$W = mg = 784\ \text{N}$$

Newton's 2nd Law of Motion

$$F = ma$$

Free Fall acceleration :

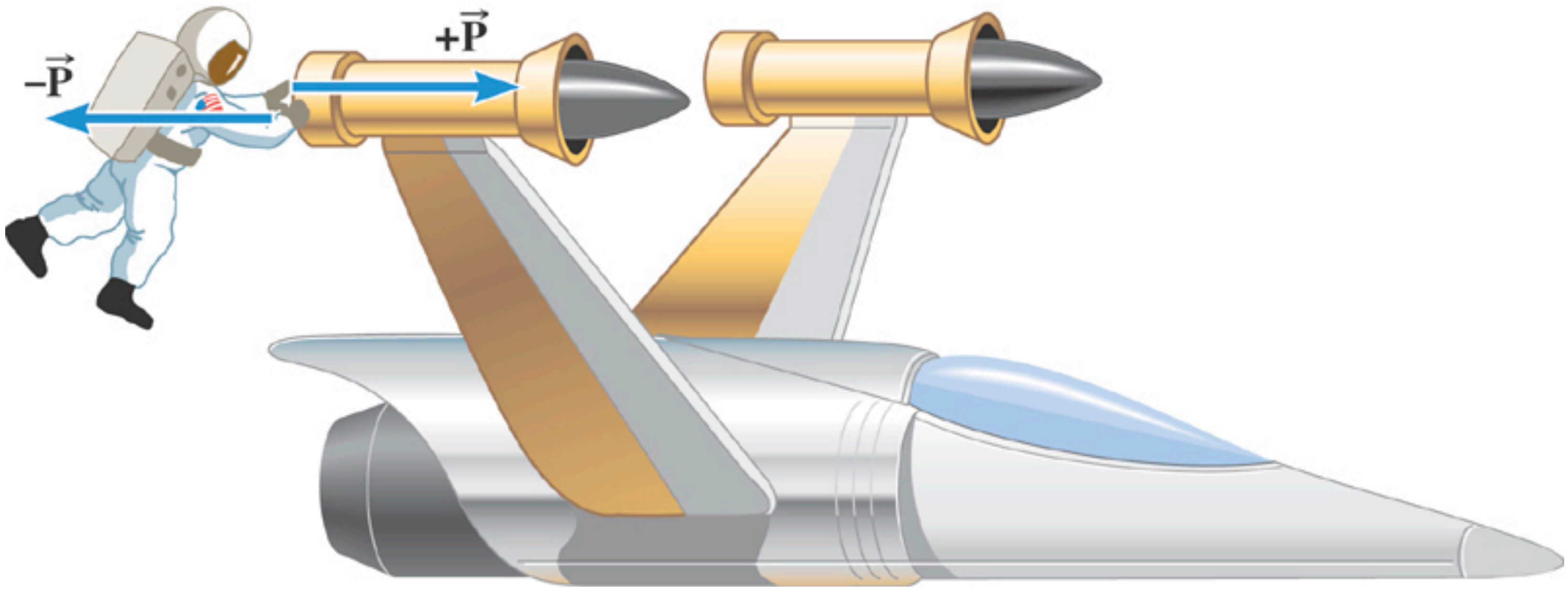
$$a = \frac{F}{m} = \frac{W}{m} = \frac{\cancel{m}g}{\cancel{m}} = g$$

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 <u>2 and ONLY 2</u> objects involved in applying Newton's 3rd law.

4.2 Newton's Laws of Motion (Third Law)



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 $\sum \vec{\mathbf{F}} = \vec{\mathbf{P}}$. (one object)

On the astronaut $\sum \vec{\mathbf{F}} = -\vec{\mathbf{P}}$. (another object)

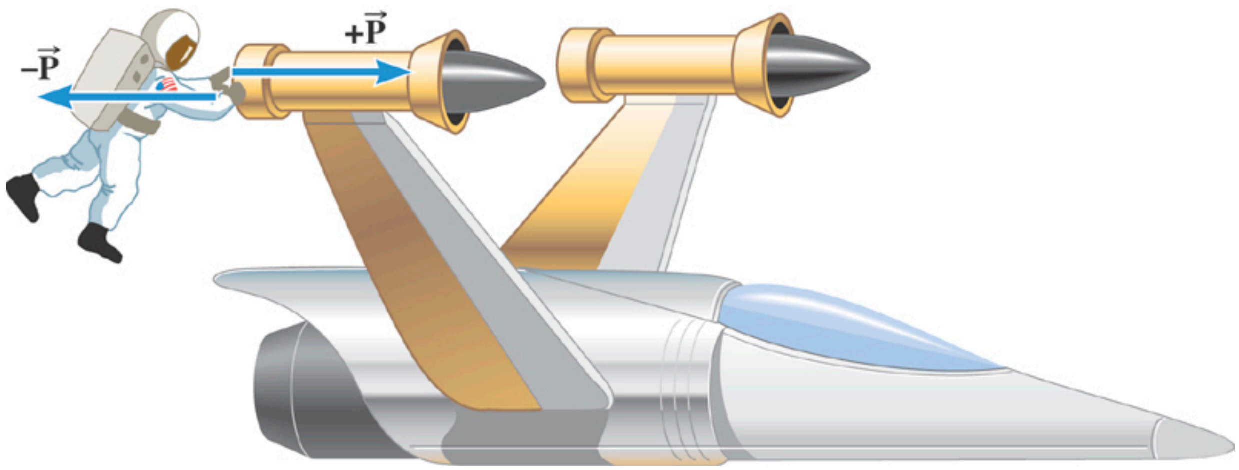
$$\vec{\mathbf{a}}_S = \frac{\vec{\mathbf{P}}}{m_S} = \frac{+36\ \text{N}}{11{,}000\ \text{kg}} = +0.0033\,\text{m/s}^2$$

Really tiny, and would not be noticed except over a very long time

$$\vec{\mathbf{a}}_A = \frac{-\vec{\mathbf{P}}}{m_A} = \frac{-36\ \text{N}}{92\ \text{kg}} = -0.39\,\text{m/s}^2$$

4.2 Newton's Laws of Motion (Third Law)

How long will these forces be able to act? Not very long!
As soon as the astronaut's arms are fully extended,
the contact with the space craft is lost and NO MORE FORCES.



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

$\vec{\mathbf{a}}_S = +0.0033\,\mathrm{m/s^2}$ $\quad v = a_S t = +0.0033\ \mathrm{m/s}\ (= 3.3\ \mathrm{mm/s})$ Really tiny

$\vec{\mathbf{a}}_A = -0.39\,\mathrm{m/s^2}$ $\quad v = a_A t = -0.39\ \mathrm{m/s}\ (= -390\ \mathrm{mm/s})$ About 1 ft/s !

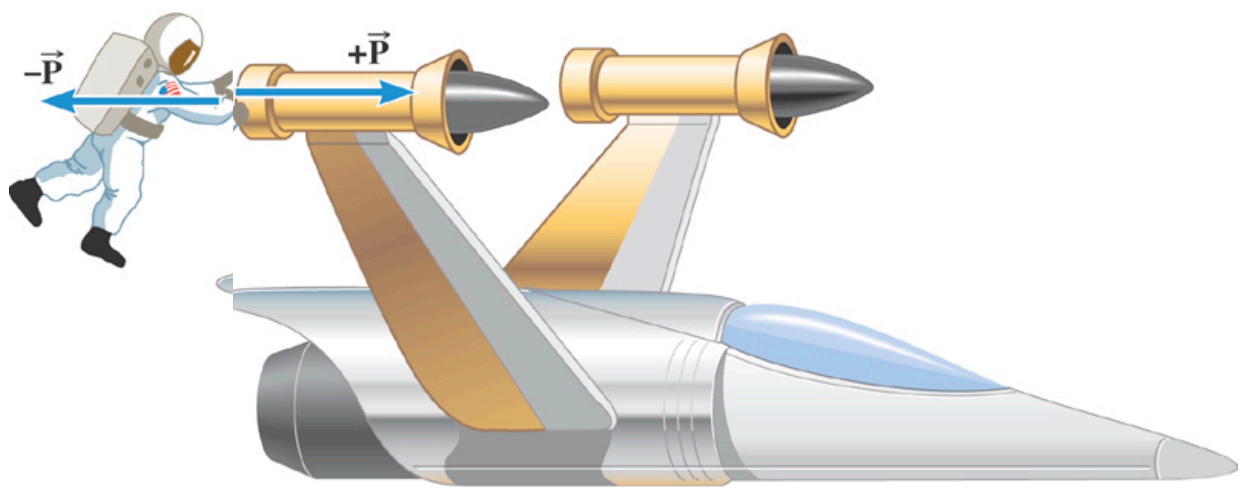
4.2 Newton's Laws of Motion (Third Law)

These two forces do not have a Net Force = 0!

$+\mathbf{P}$ acts on the spacecraft

$-\mathbf{P}$ acts on the astronaut

To use the Net force and Newton's 2nd law, all the forces being summed must act on the same object.



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

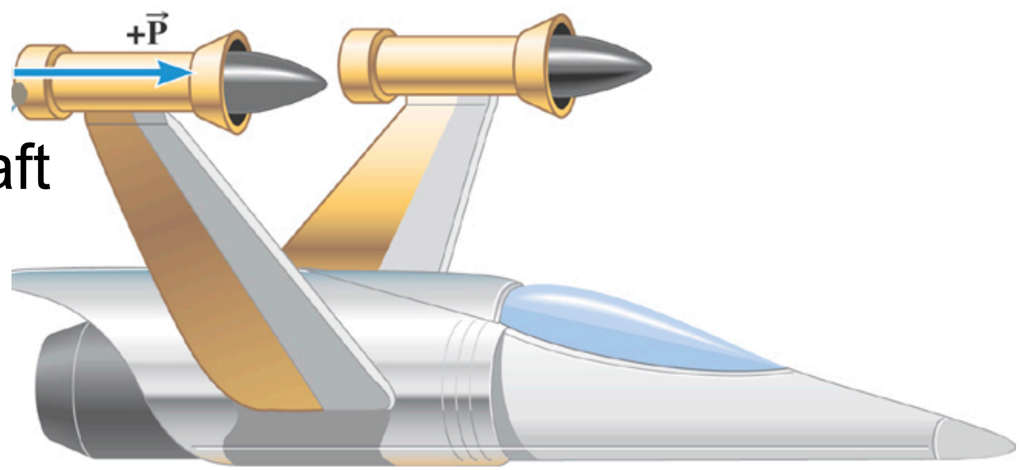
These two forces do not have a Net Force = 0!

+**P** acts on the spacecraft

–**P** acts on the astronaut

To use the Net force and Newton's 2nd law, all the forces being summed must act on the same object.

Astronaut's push
Acting on spacecraft



4.2 Newton's Laws of Motion (Third Law)

These two forces do not have a Net Force = 0!

$+\mathbf{P}$ acts on the spacecraft

$-\mathbf{P}$ acts on the astronaut

To use the Net force and Newton's 2nd law, all the forces being summed must act on the same object.

Spacecraft's push
acting on the astronaut.

Warning:

Newton's 3st law can appear to be violated if you can't see the resulting movement (too small) of one of the two objects.

Examples (clicker questions):

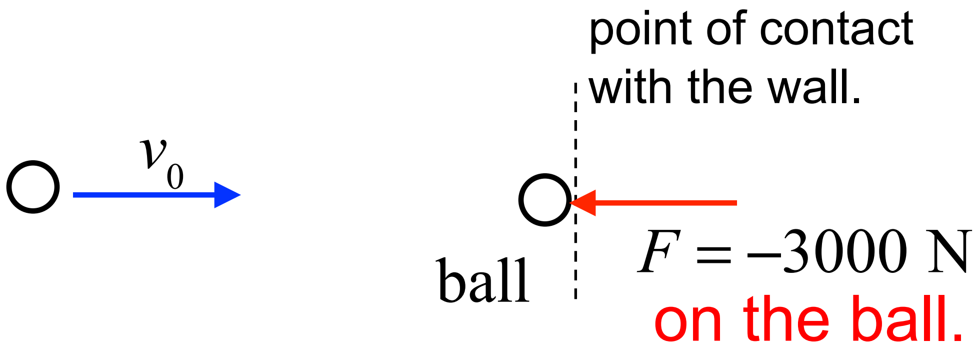
- **Ball** bouncing off a **wall**.
- **Mass** sliding on a **table** w/friction.
- **Bat** hitting a **baseball**
- **Gun** firing a **bullet**

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.

Clicker Question 4.7

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



a) $F = -3000$ N

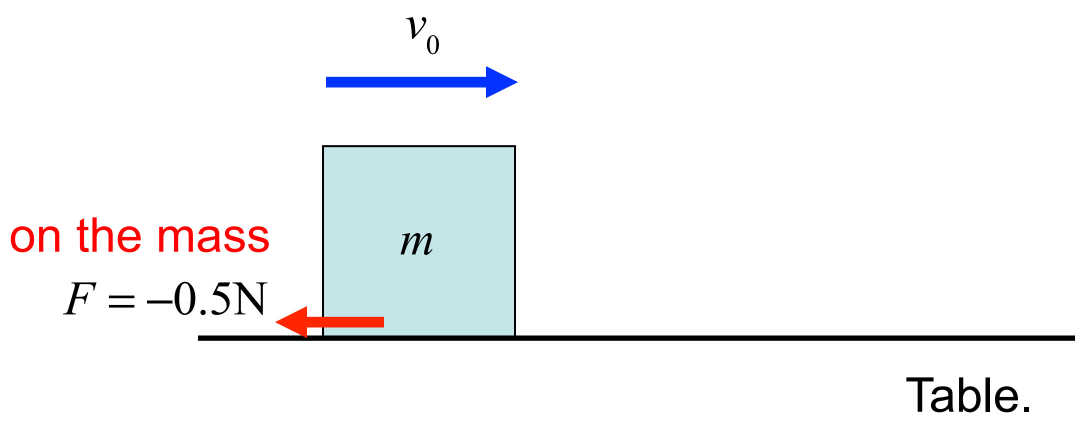
b) $F = +3000$ N

c) $F = 0$ N

d) $F = 60$ N

e) A ball cannot make a force.

Clicker Question 4.8



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

a) $F = +0.5\,\text{N}$

b) $F = -0.5\,\text{N}$

c) $F = 0\,\text{N}$

d) $F = 60\,\text{N}$

e) A mass cannot make a force.

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.

Newton's laws of force and motion

1. An object continues in a state of rest or in a state of motion at a constant speed *along a straight line*, unless compelled to change that state by a net force. (One object)

2. When a net external force acts on an object of mass *m*, the acceleration that results is directly proportional to the net force and has a magnitude that is inversely proportional to the mass. The direction of the acceleration is the same as the direction of the net force.

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$ (One object)

3. 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.

(Two objects in contact or attracted by gravity)

Clicker Question 4.9

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

Hint: Acceleration is the same for car and driver

1) Determine the acceleration

2) then force on driver (using driver mass)

Clicker Question 4.10

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.

a) The force acting on the smaller mass is always the largest.

b) The force acting on the larger mass is always the largest.

c) The force acting on the vehicle with the highest speed is the largest .

d) The force acting on the vehicle with the smallest speed is the largest.

e) The force acting on the two vehicles is always exactly the same.

Example

There are two ropes and each applies a force of +40 N on mass of 20 kg. However, the mass exhibits an acceleration of –10 m/s². What other force (magnitude and direction) acts on the object?

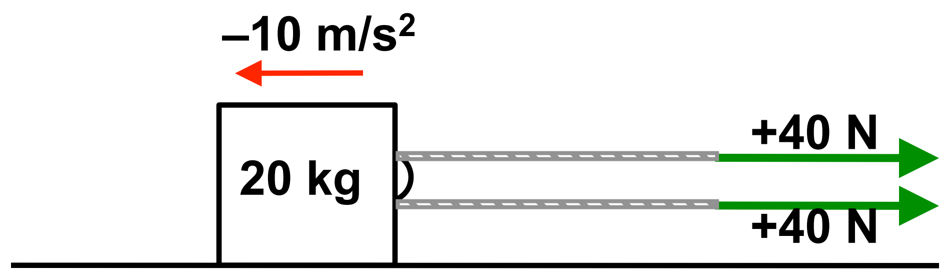
a) $F_3 = 200\text{ N}$

b) $F_3 = 80\text{ N}$

c) $F_3 = -280\text{ N}$

d) $F_3 = -100\text{ N}$

e) $F_3 = -80\text{ N}$



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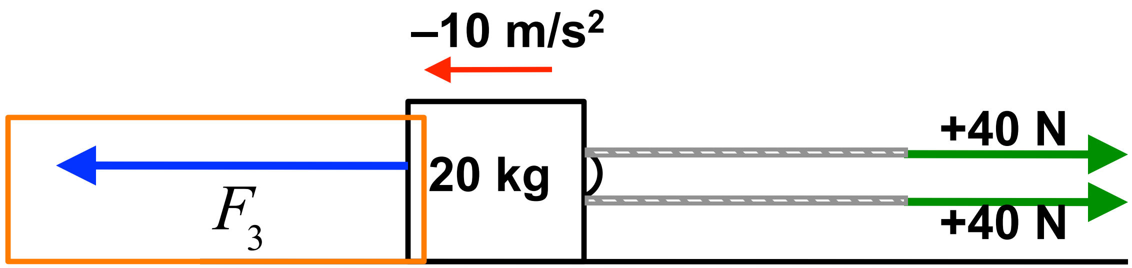
c) $F_3 = -280\ \text{N}$

d) $F_3 = -100\ \text{N}$

e) $F_3 = -80\ \text{N}$



$$F_{Net} = F_3 + (+80\ \text{N});$$

$$F_{Net} = ma;$$

$$F_3 = ma - (+80\ \text{N})$$

$$= (20\,\text{kg})(-10\,\text{m/s}^2) - 80\,\text{N}$$

$$= -280\ \text{N}$$

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 single force will make the Net Force acting on the ball equal to zero?

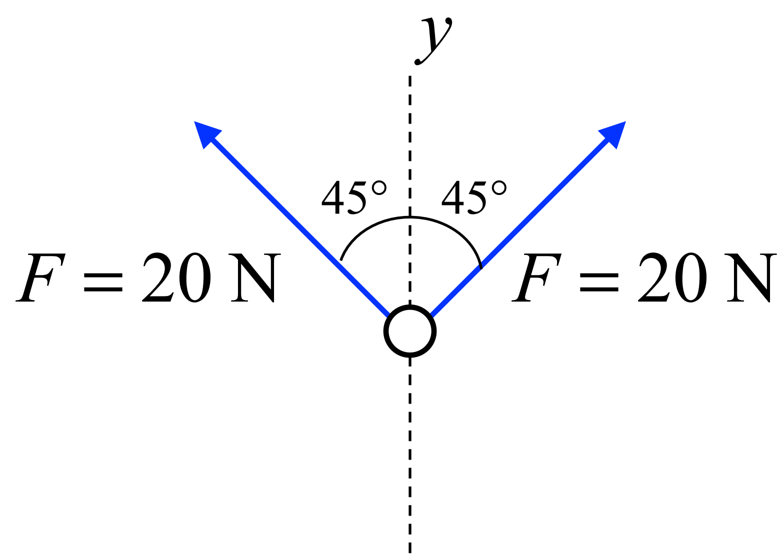
a) -40 N

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 single force will make the Net Force acting on the ball equal to zero?

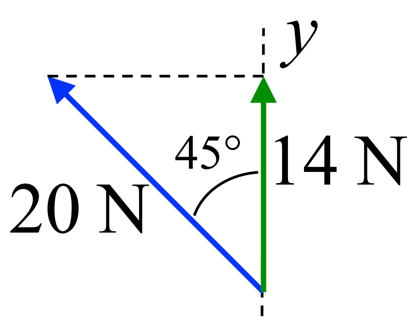
a) – 40 N

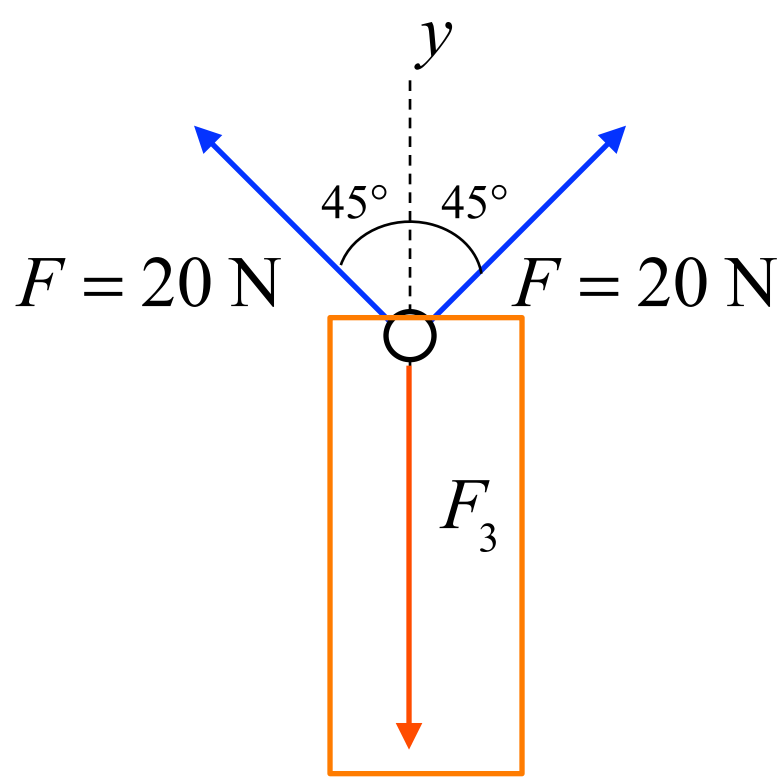
b) – 14 N

c) – 32 N

d) – 18 N

e) – 28 N





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

$$F_3 = -2\left(F\cos 45°\right) = -28\,\text{N}$$

4.2 *Newton's Laws of Motion (Gravity and the Body)*

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.

4.2 Newton's Laws of Motion (Gravity and the Body)

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.

A) In your arms
B) In your legs

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.

A) In your arms
B) In your legs

Let go of the 100 m high diving board.

While gravity accelerates you downward, what do you feel ?

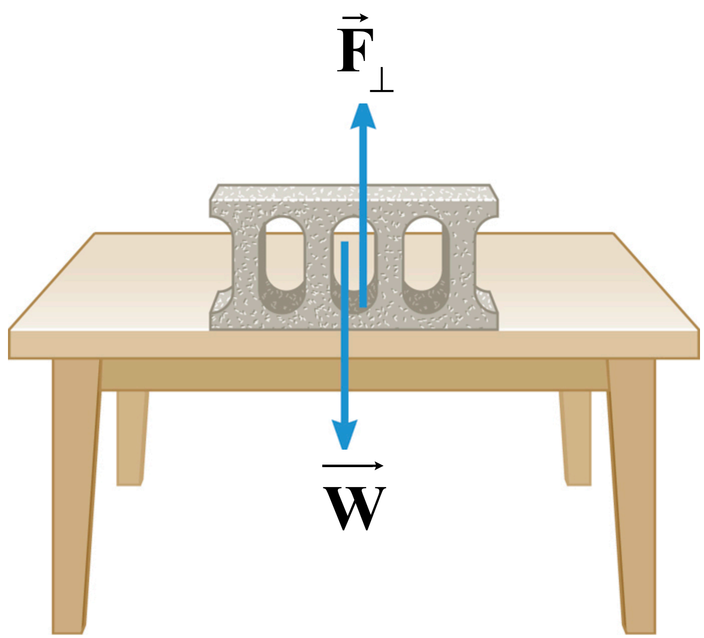
You don't feel stretched, and you don't feel compressed.
You feel "weightless", yes, but your weight is still $W = mg$.

A) Stretched & compressed
B) Weightless

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 $\vec{\mathbf{n}}$



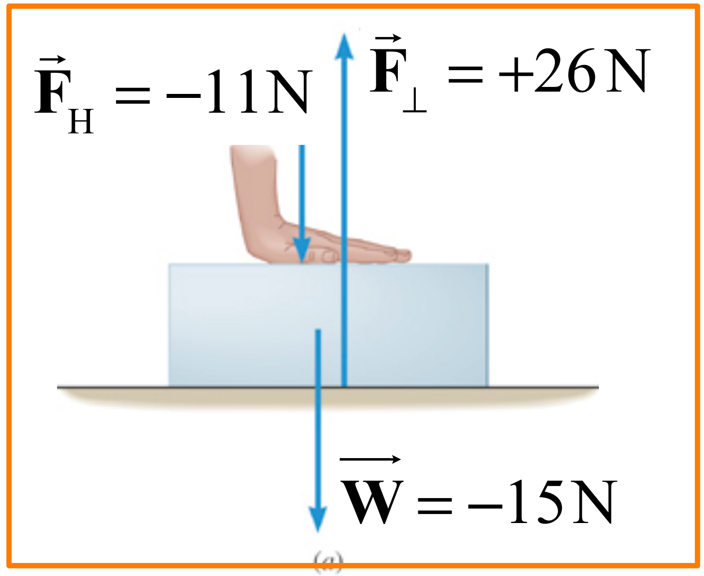
4.2 Newton's Laws of Motion (Normal Forces)

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.

Net force must be zero

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

$$0 = \mathbf{F}_{\perp} + \left(-11\text{ N}\right) + \left(-15\text{ N}\right)$$



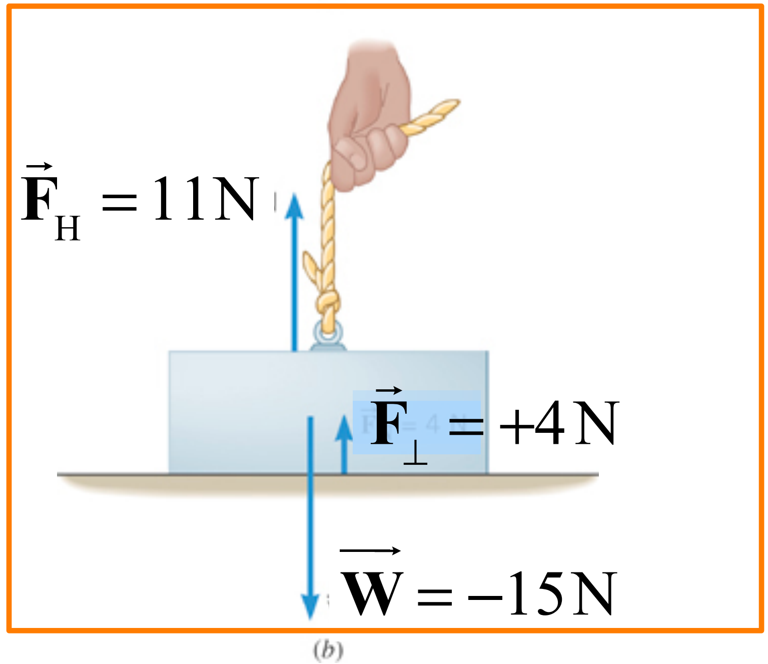
Solve for normal force

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

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

$$0 = \vec{\mathbf{F}}_{\perp} + 11\text{ N} + \left(-15\text{ N}\right)$$

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



4.2 Newton's Laws of Motion (Normal Forces)

Apparent Weight = Normal force acting on an object

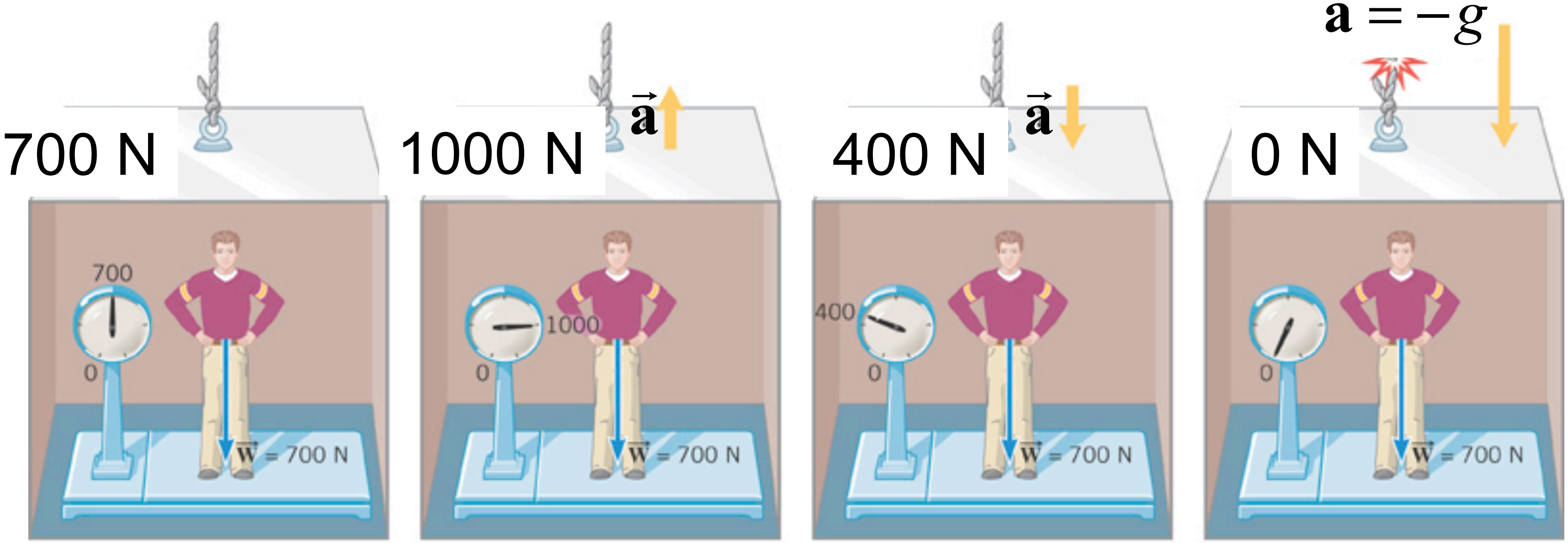
The apparent weight of an object is the reading of the scale.

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.

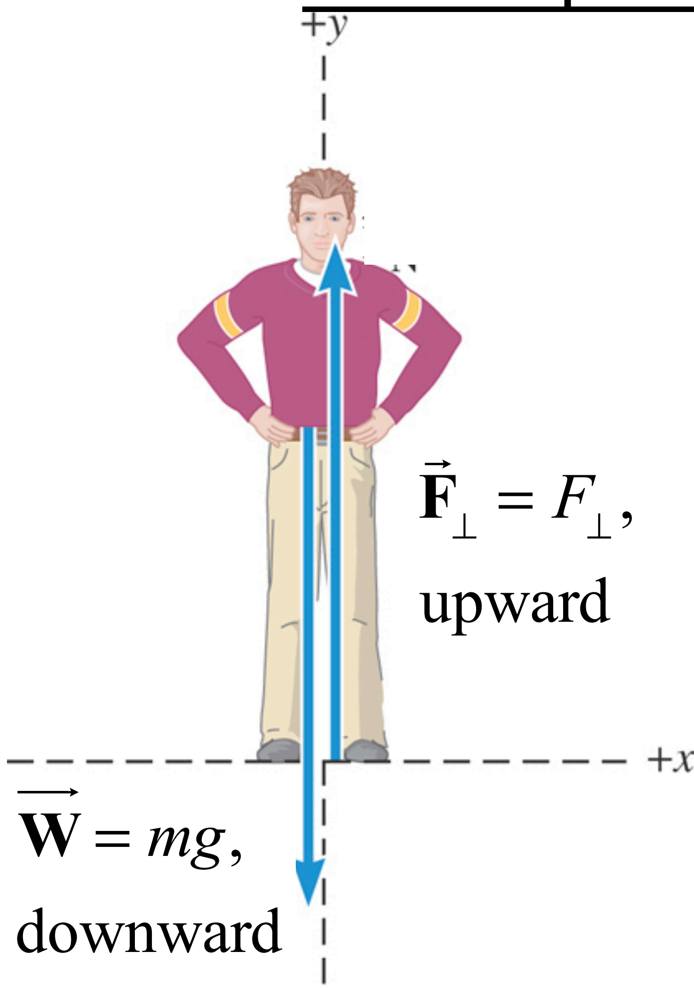
$\vec{\mathbf{a}} = -g$



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

4.2 Newton's Laws of Motion (Normal Forces)

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 ($F_\perp$) — true weight (mg)

acceleration upward: apparent weight > true weight

acceleration downward: apparent weight < true weight

constant velocity up or down: apparent weight = true weight