Chapter 4

Forces and Newton's Laws of Motion

continued

4.2 Newton's Laws of Motion (First Law)

Warning:

Newton's 1st law can appear to be violated if you don't recognize the existence of contact forces.

Newton's 1st law: for an object to *remain at rest*, or *move with constant speed & direction*, the Net Force acting on it must be ZERO.

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).

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

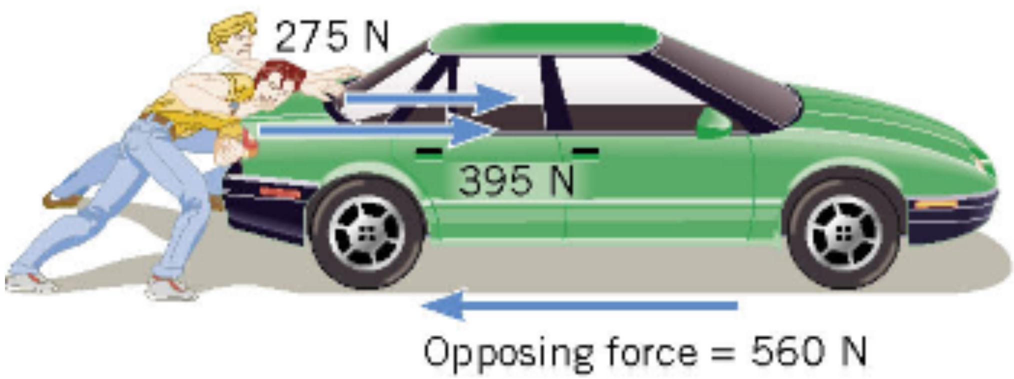
4.2 Newton's Laws of Motion (Second Law)

Table 4.1 Units for Mass, Acceleration, and Force

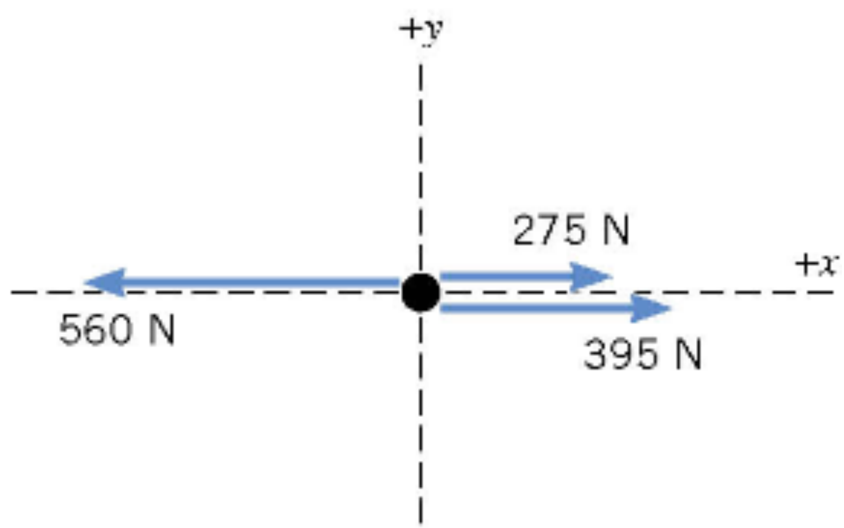
System	Mass	Acceleration	Force
SI	kilogram (kg)	meter/second^2 (m/s^2)	newton (N)
CGS	gram (g)	centimeter/second^2 (cm/s^2)	dyne (dyn)
BE	slug (sl)	foot/second^2 (ft/s^2)	pound (lb)

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

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

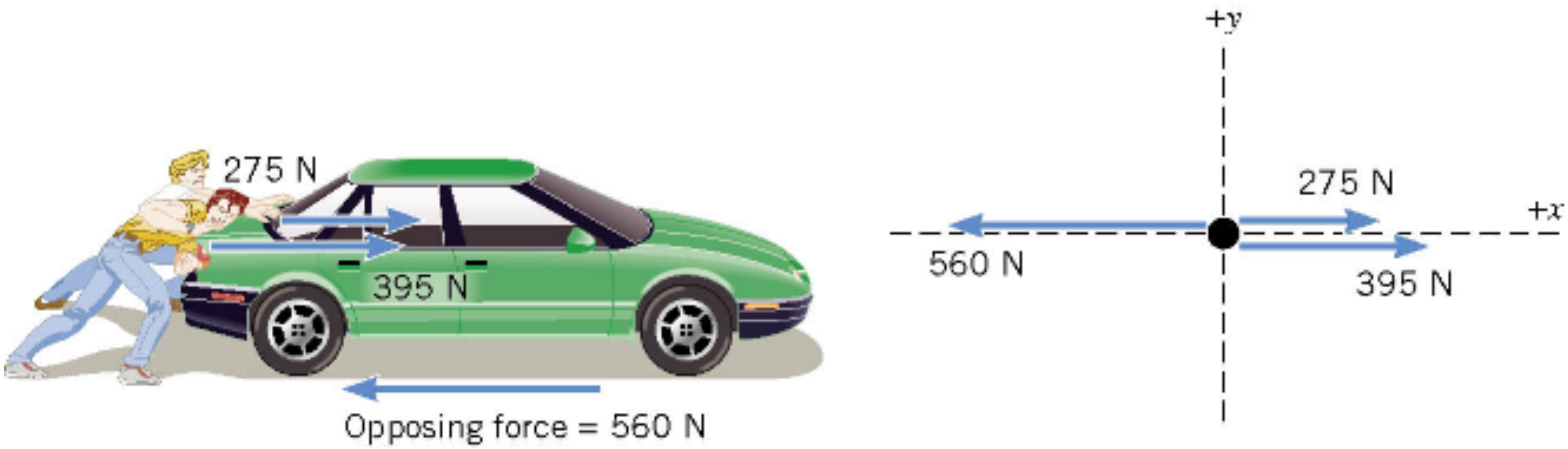


(a)



(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

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

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.

$\Downarrow$

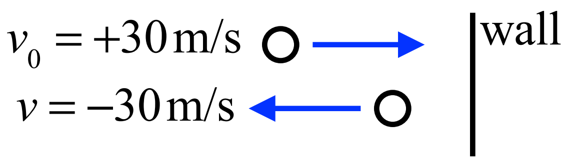
Once the Net Force acting on an object and Newton's 2nd law are used to calculate the object's acceleration vector, future changes of the position and velocity can be predicted.

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

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?

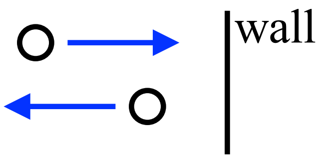
one object

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?

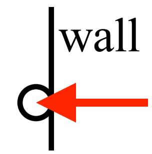
$v_0 = +30\,\text{m/s}$

$v = -30\,\text{m/s}$



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

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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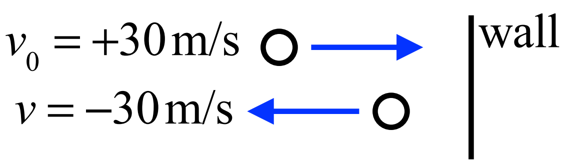

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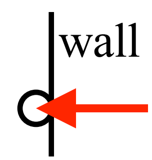
If the paddle ball has a mass of 0.2 kg, what is the force that the wall applied to the ball?

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



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

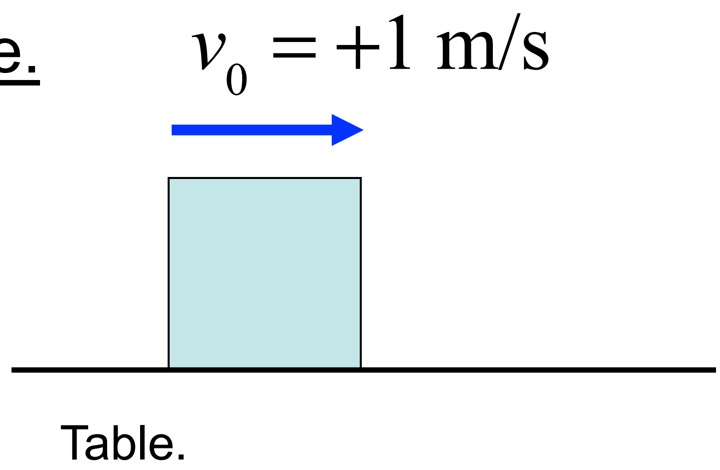
Force on ball is to the LEFT

Magnitude of 600 N

(~120 lbs)

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

<u>A mass sliding on a table.</u>



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.

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

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

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

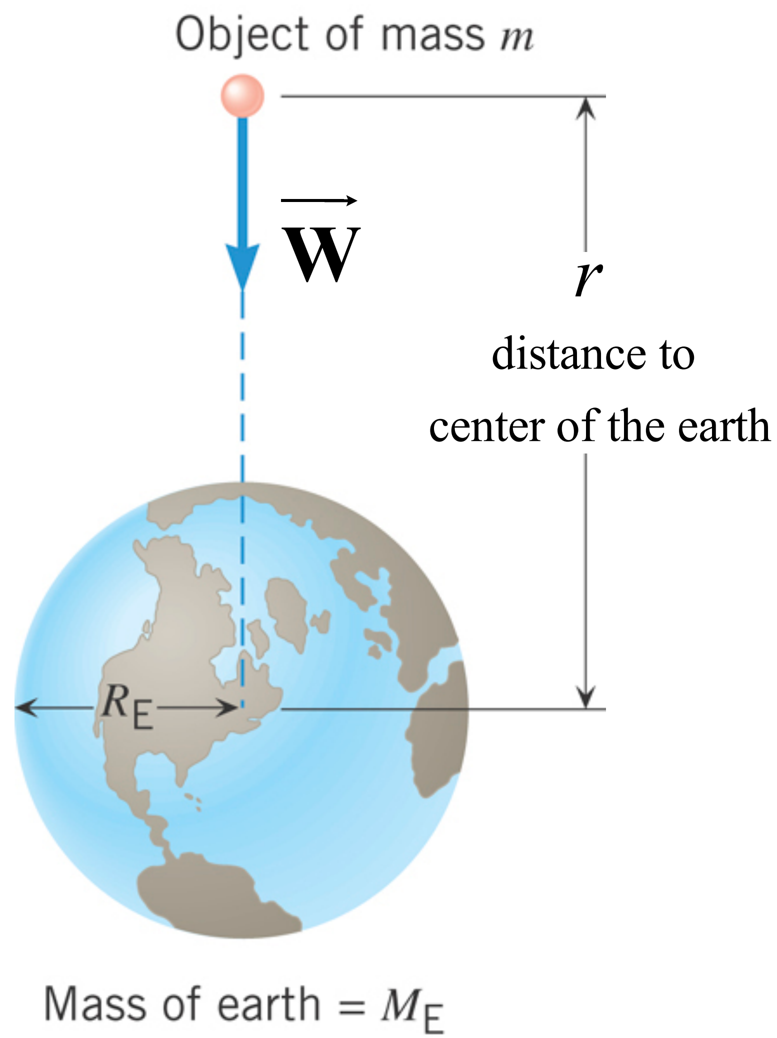
WEIGHT(magnitude) of the mass m

$$W = mg$$

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:

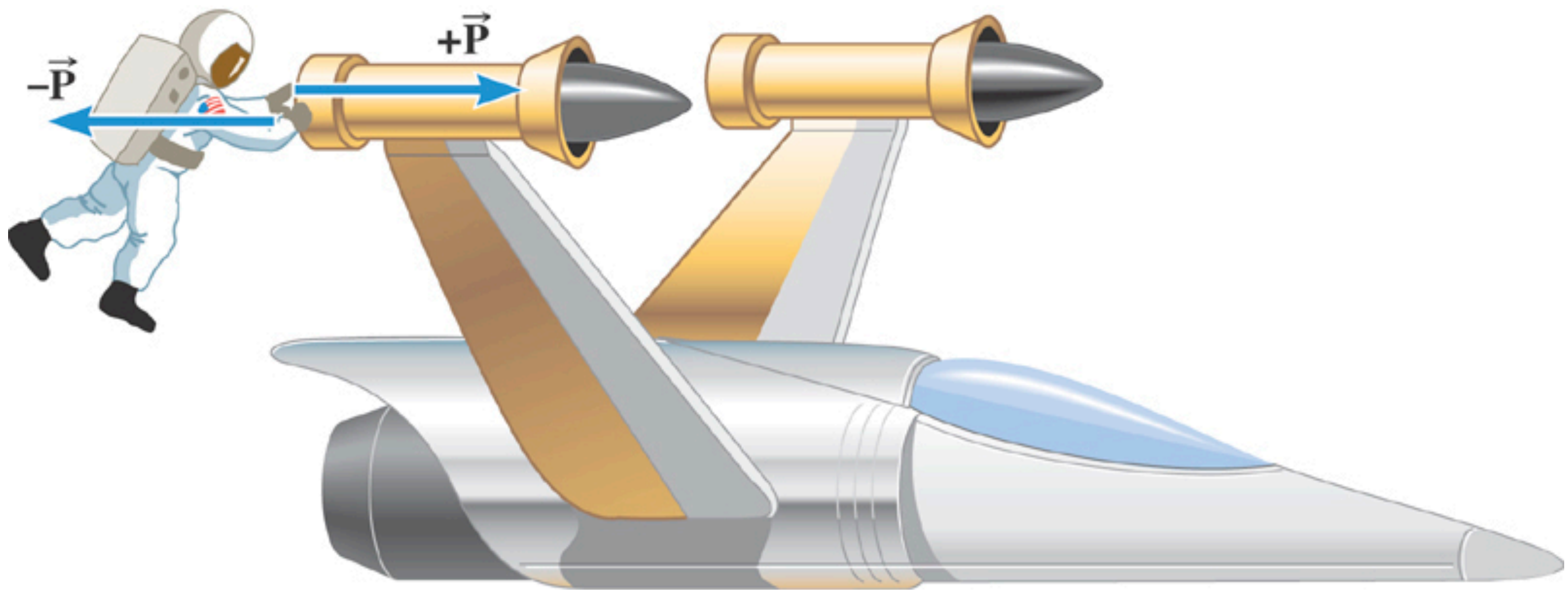
$$a = \frac{F}{m} = \frac{W}{m} = \frac{\cancel{m}g}{\cancel{m}} = g$$

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)

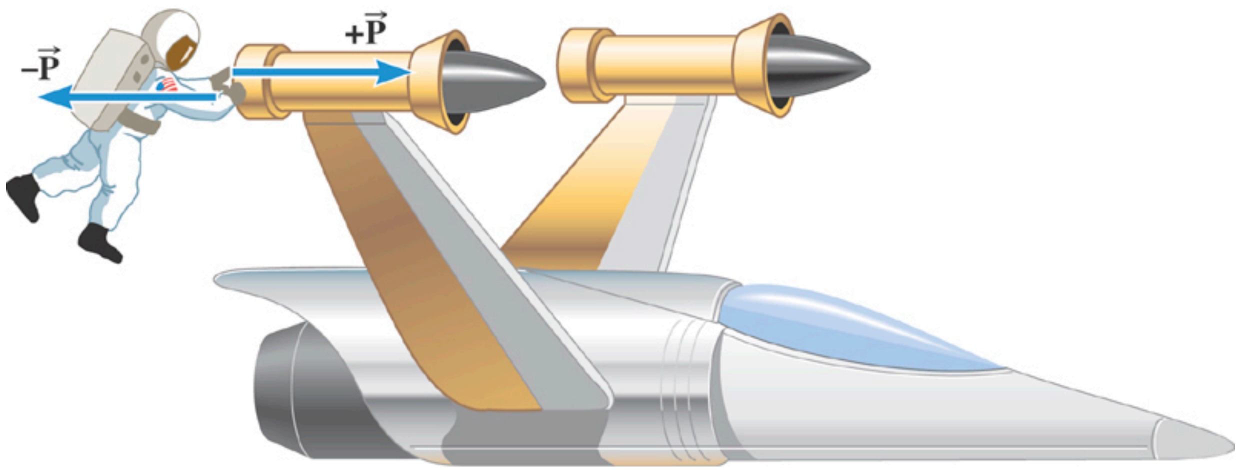
$$\vec{\mathbf{a}}_S = \frac{\vec{\mathbf{P}}}{m_S} = \frac{+36\ \text{N}}{11{,}000\ \text{kg}} = +0.0033\,\text{m/s}^2$$

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.

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

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

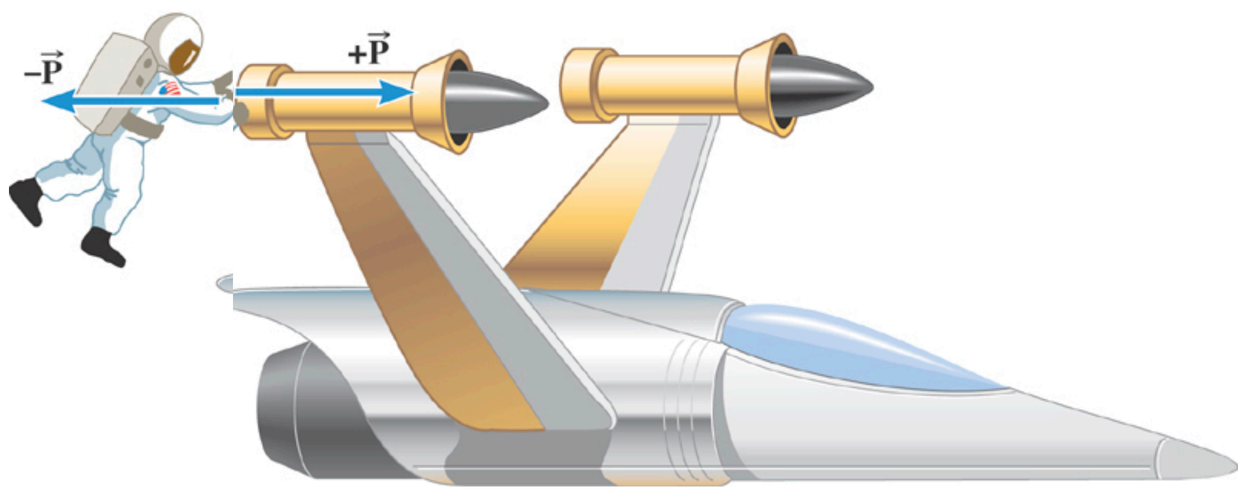
4.2 Newton's Laws of Motion (Third Law)

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.



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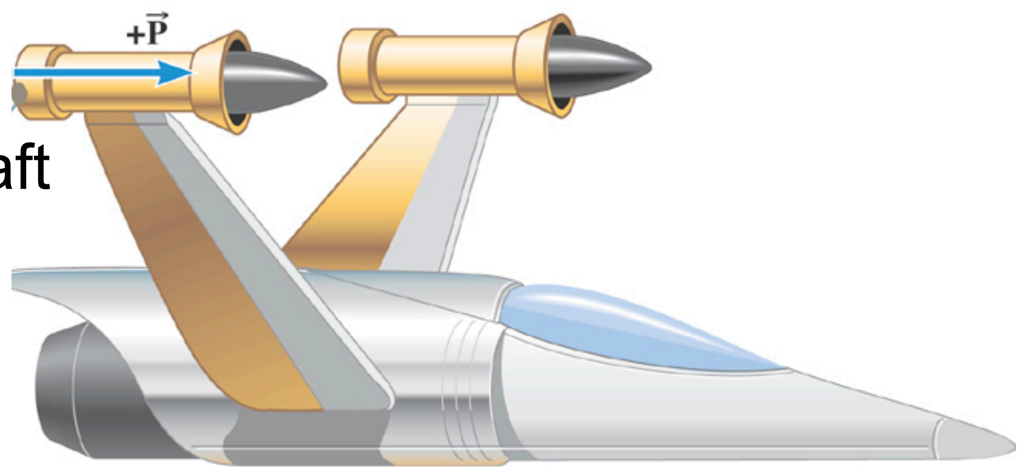
Astronaut's push
Acting on spacecraft



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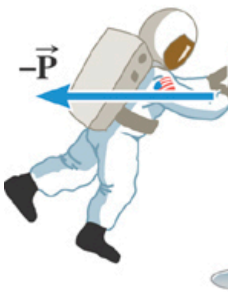

Spacecraft's push
acting on the astronaut.

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.

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)