Chapter 4

Forces and Newton's Laws of Motion

continued

4.2 Newton's Laws of Motion (First Law)

Warning:

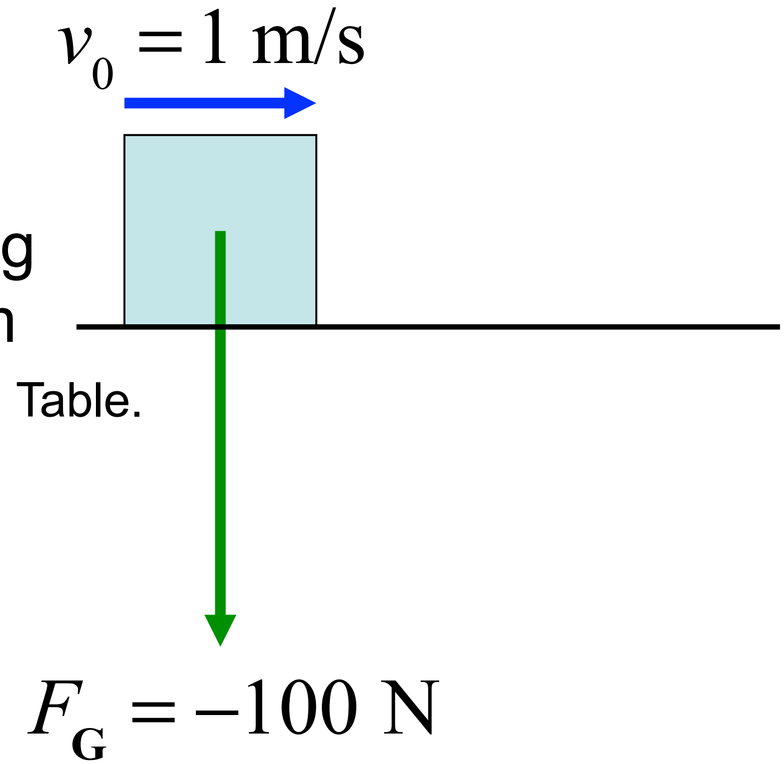
Newton's 1st law can appear to be violated if you don't recognize the existence of contact forces.

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.

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.

Clicker Question 4.4

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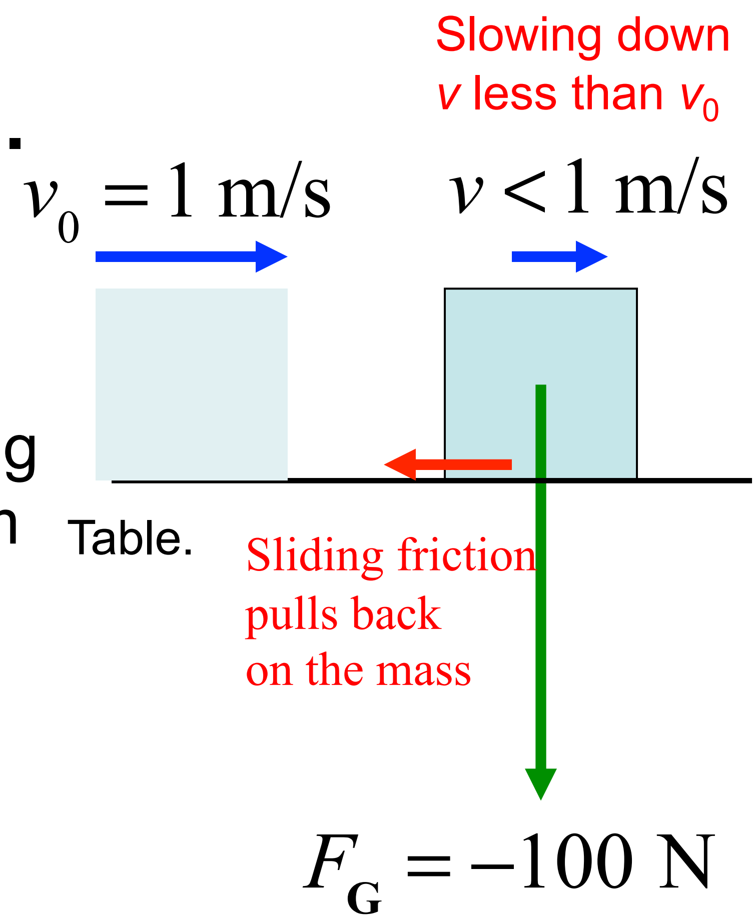


a) Upward

b) Downward

c) To the right (+)

d) To the left (–)

e) A table can't make a force.

Changing velocity means
Net Force is NOT 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.

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

Sum of forces
acting on 1 object

SI Unit for Force

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

Note: it has the same units as ma.

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

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

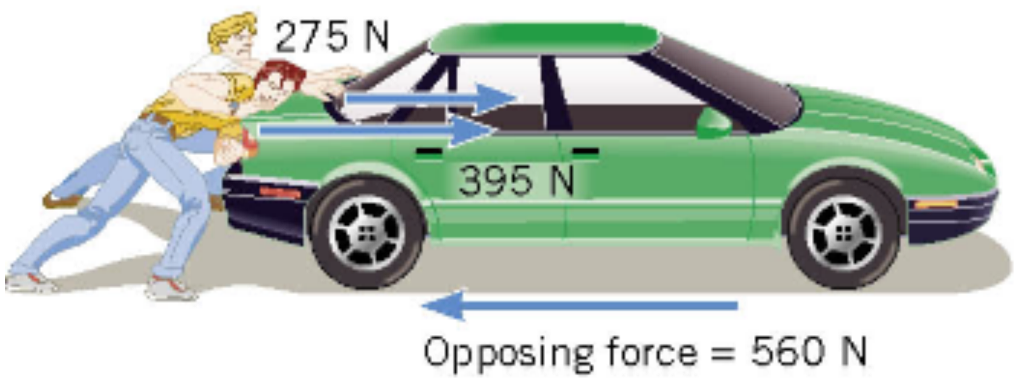
4.2 Newton's Laws of Motion (Second Law)

Table 4.1 Units for Mass, Acceleration, and Force

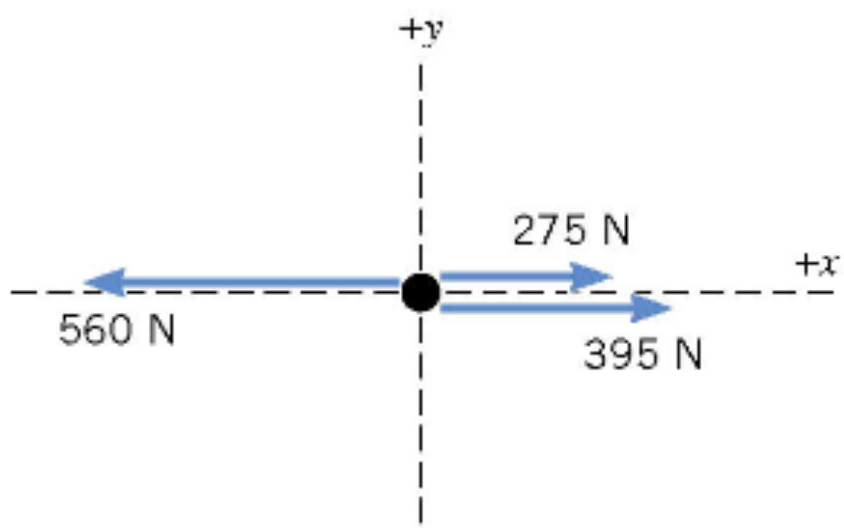
System	Mass	Acceleration	Force
SI	kilogram (kg)	meter/second^2 (m/s^2)	newton (N)
CGS	gram (g)	centimeter/second^2 (cm/s^2)	dyne (dyn)
BE	slug (sl)	foot/second^2 (ft/s^2)	pound (lb)

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

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

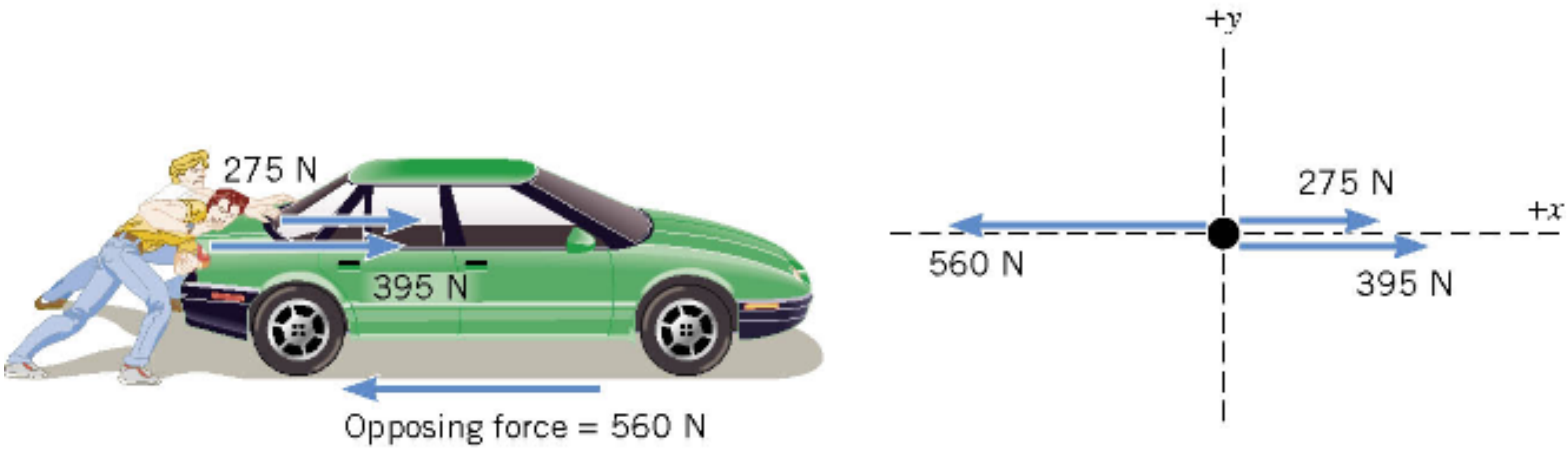


(a)



(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

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

Clicker Question 4.5

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

a) $0.059\ \mathrm{m}$

b) $10\ \mathrm{m}$

c) $0.59\ \mathrm{m}$

d) $3.0\ \mathrm{m}$

e) $0.3\ \mathrm{m}$

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b) $10\ \text{m}$

c) $0.59\ \text{m}$

d) $\boxed{3.0\ \text{m}}$

e) $0.3\ \text{m}$

$$
\begin{aligned}
x &= v_0 t + \tfrac{1}{2} a t^2 \\
&= 0 + 0.5(0.059\ \text{m/s}^2)(10\ \text{s})^2 \\
&= 3.0\ \text{m}
\end{aligned}
$$

4.2 Newton's Laws of Motion (Second Law)

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.

$\Downarrow$

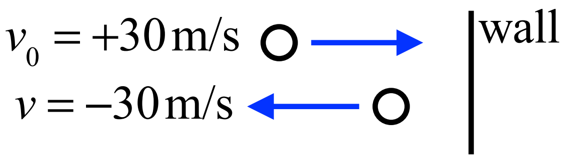
Once the Net Force acting on an object and Newton's 2nd law are used to calculate the object's acceleration vector, future changes of the position and velocity can be predicted.

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

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?

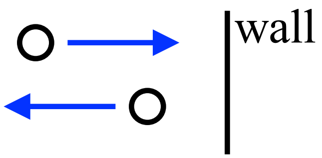
one object

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?

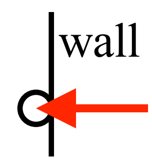
$v_0 = +30\,\text{m/s}$

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



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

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

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

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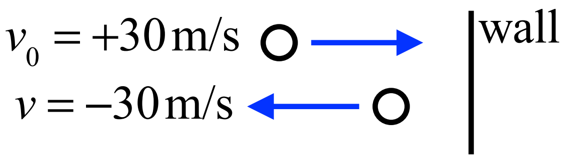
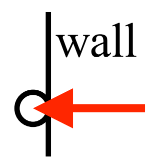


$$a = \frac{(v - v_0)}{t} = \frac{\left[-30 - (+30)\right]\text{m/s}}{.02\text{ s}} = -3000\text{ m/s}^2$$

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

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



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

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>

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

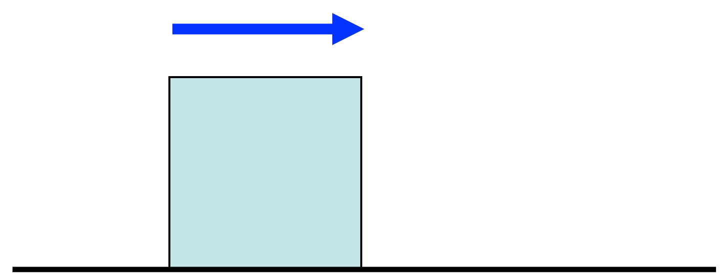


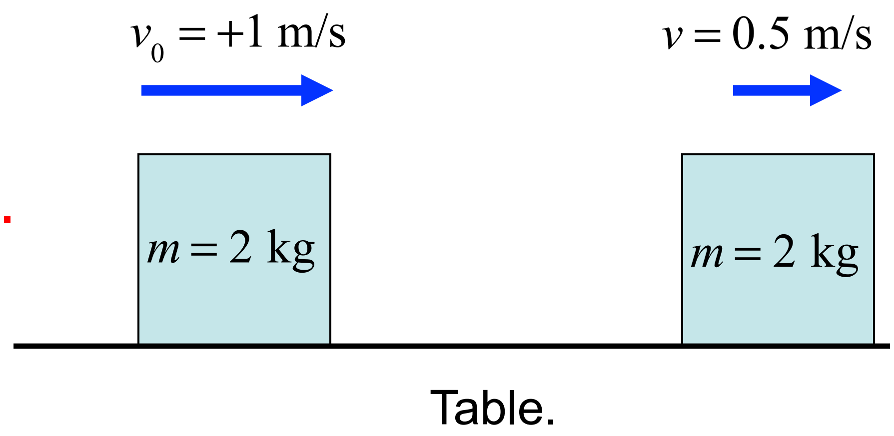
Table.

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.

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

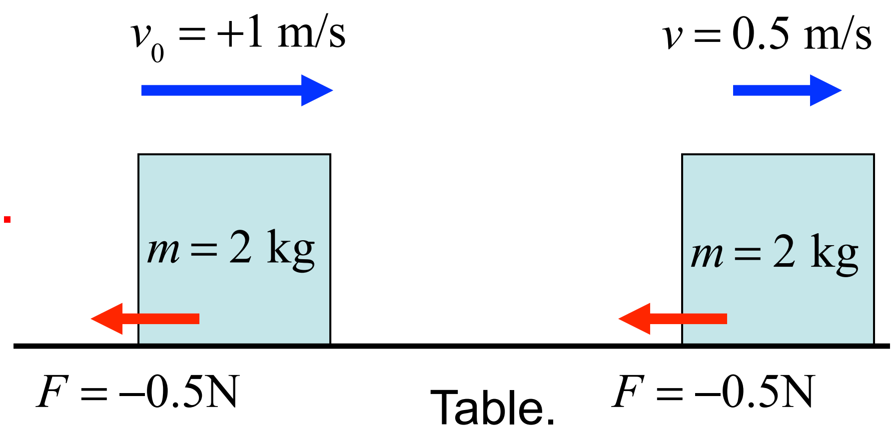
c) $F = -1.0\,\text{N}$

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

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

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.



Acting on the mass is what force (magnitude and direction) that causes it to lose speed?

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

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

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

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

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

$$a = \frac{(v - v_0)}{t} = \frac{[0.50 - 1.0]\text{m/s}}{2.0\text{ s}} = -0.25\text{ m/s}^2$$

$$F = ma = (2.0\text{ kg})(-0.25\text{ m/s}^2) = -0.5\text{ kg-m/s}^2$$
$$= -0.5\text{ N}$$

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

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

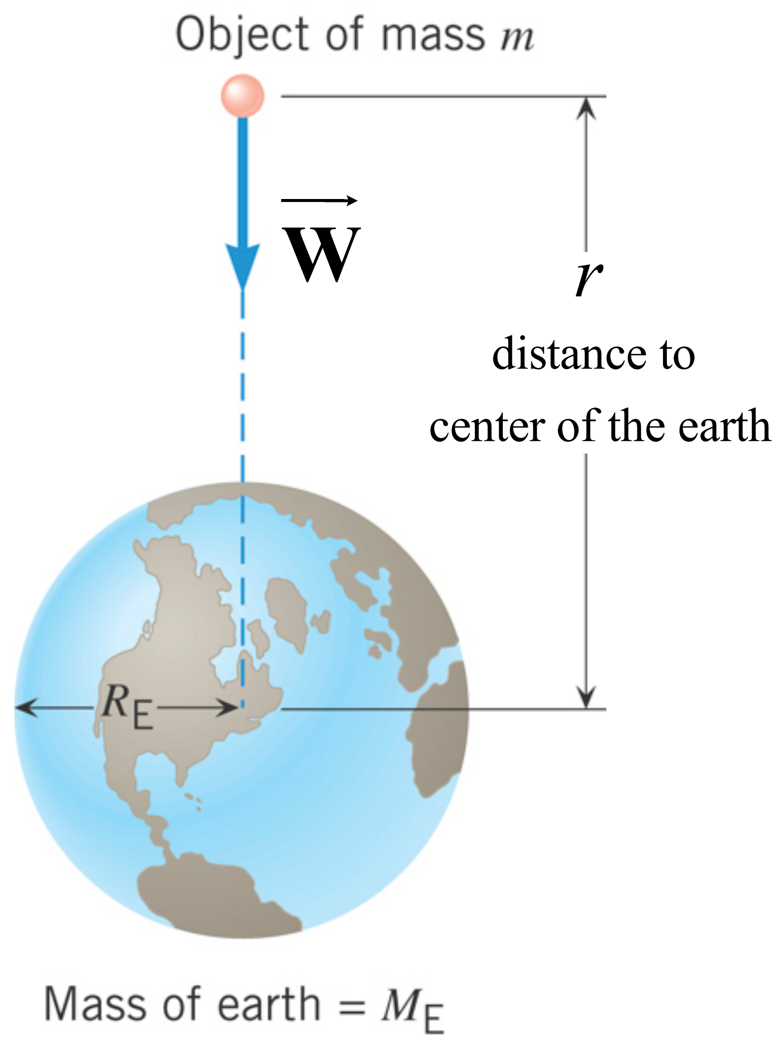
WEIGHT(magnitude) of the mass m

$$W = mg$$

Your WEIGHT

WEIGHT DEFINITION

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



Near the earth's surface

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

$$\boxed{r = R_E = 6.38\times 10^6\ \text{m}}$$

Radius of the earth

$$= \left(6.67\times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2\right)\frac{\left(5.97\times 10^{24}\ \text{kg}\right)}{\left(6.37\times 10^6\ \text{m}\right)^2}$$

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

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:

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