Chapter 4

Forces and Newton's Laws of Motion

continued

Quiz to follow

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.

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

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)

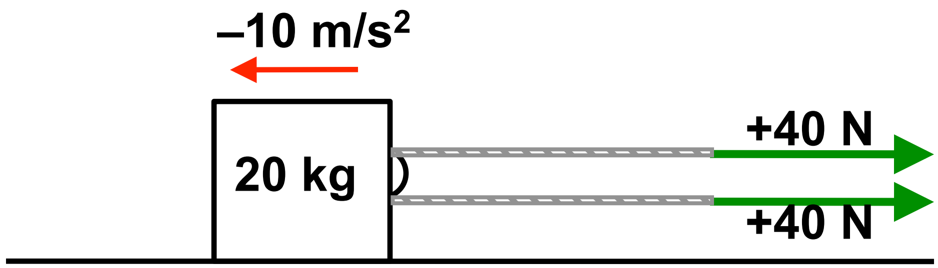
Quiz 3

1. **C&J page 90 (top), Check Your Understanding #3**

2. **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

3. **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.

4. 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) $F_3 = 200\ \mathrm{N}$

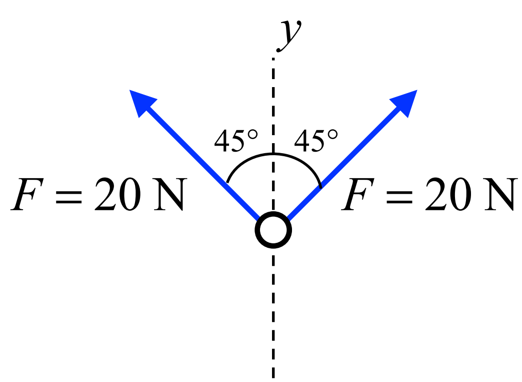
b) $F_3 = 80\ \mathrm{N}$

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

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

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

5. 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) $-40\ \mathrm{N}$

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

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

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

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

Quiz 3

d) $\boxed{\text{Net Force} \Leftrightarrow \text{acceleration}}$

1. **C&J page 90 (top), Check Your Understanding #3**

2. **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) $20{,}000\,\text{N}$

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

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

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

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

$$a = \frac{F_B}{m_B} = \frac{20{,}000 \text{ N}}{2100 \text{ kg}} = 9.5 \text{ m/s}^2;\ \text{for car, and for driver.}$$

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

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

   a) The largest force acts on the smallest mass.

   b) The largest force acts on the largest mass.

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

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

   e) $\boxed{\text{The same force acts on both vehicles.}}$

$\boxed{\text{Newton's 3}^{\text{rd}}\text{ law!}}$

4. 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 third force (magnitude and direction) acts on the object?

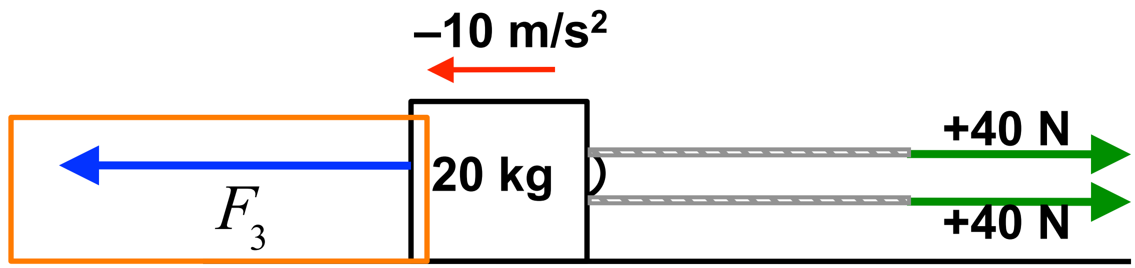
a) $F_3 = 200\ \text{N}$

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

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

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

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



$$\boxed{\begin{aligned} &F_{Net} = F_3 + \left(+80\ \text{N}\right); \quad F_{Net} = ma; \\ &F_3 = ma - \left(+80\ \text{N}\right) = (20\,\text{kg})(-10\,\text{m/s}^2) - 80\,\text{N} = -280\ \text{N} \end{aligned}}$$

5. 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?

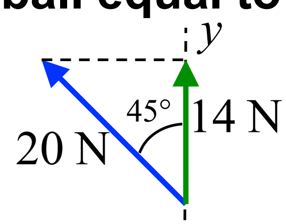
a) $-40\ \text{N}$

b) $-12\ \text{N}$

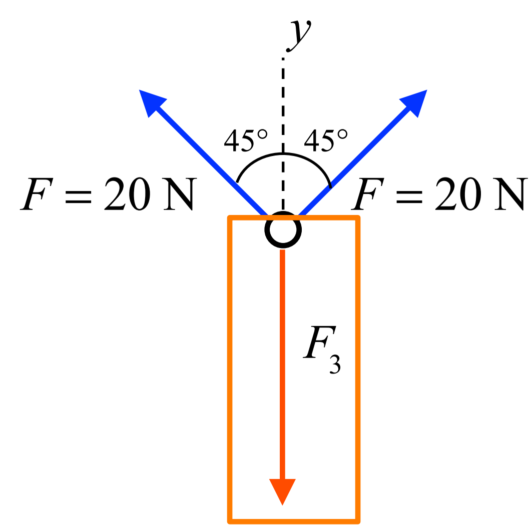
c) $-32\ \text{N}$

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

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



$$\boxed{\begin{aligned} &y: F_{Net} = 0 = 2\left(F\cos 45°\right) + F_3 \\ &F_3 = -2\left(F\cos 45°\right) = -28\,\text{N} \end{aligned}}$$



Newton's Law of Universal Gravitation

Every particle in the universe exerts an attractive force on every other particle.

A particle is a piece of matter, small enough in size to be regarded as a mathematical point.

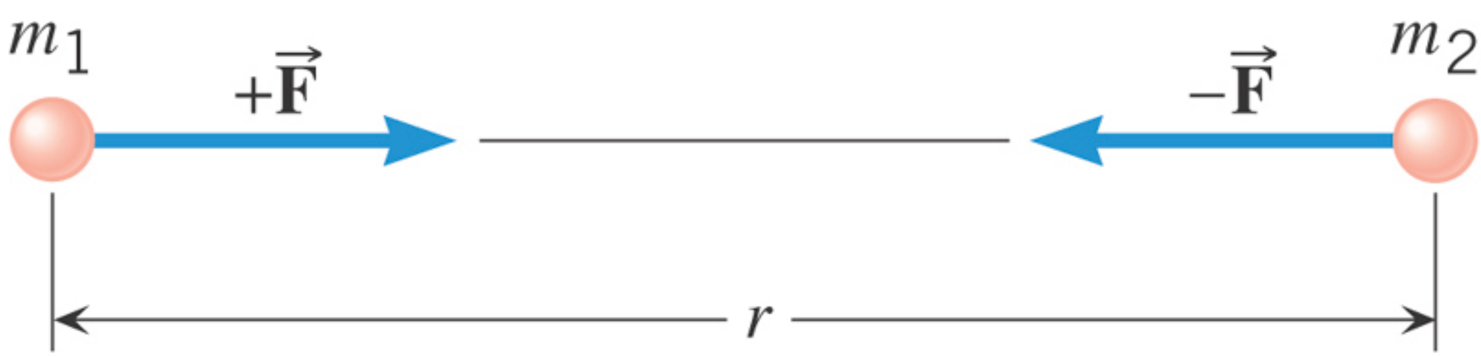
The force that each exerts on the other is directed along the line joining the particles.

4.7 The Gravitational Force

For two particles that have masses m_1 and m_2 and are separated by a distance r, the force has a magnitude given by

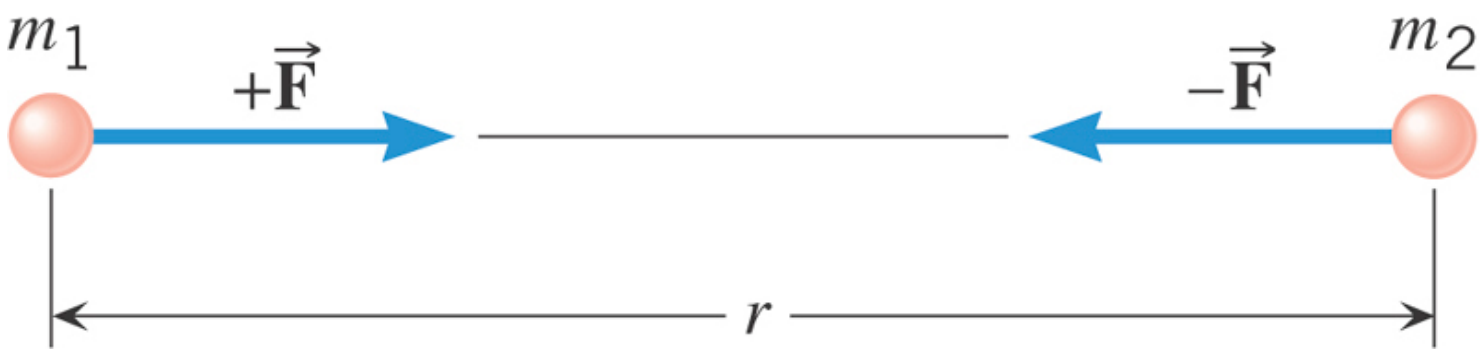
$$F = G\frac{m_1 m_2}{r^2}$$

$$G = 6.673\times 10^{-11}\ \mathrm{N\cdot m^2/kg^2}$$



the same magnitude of force acts on each mass, no matter what the values of the masses.

4.7 The Gravitational Force

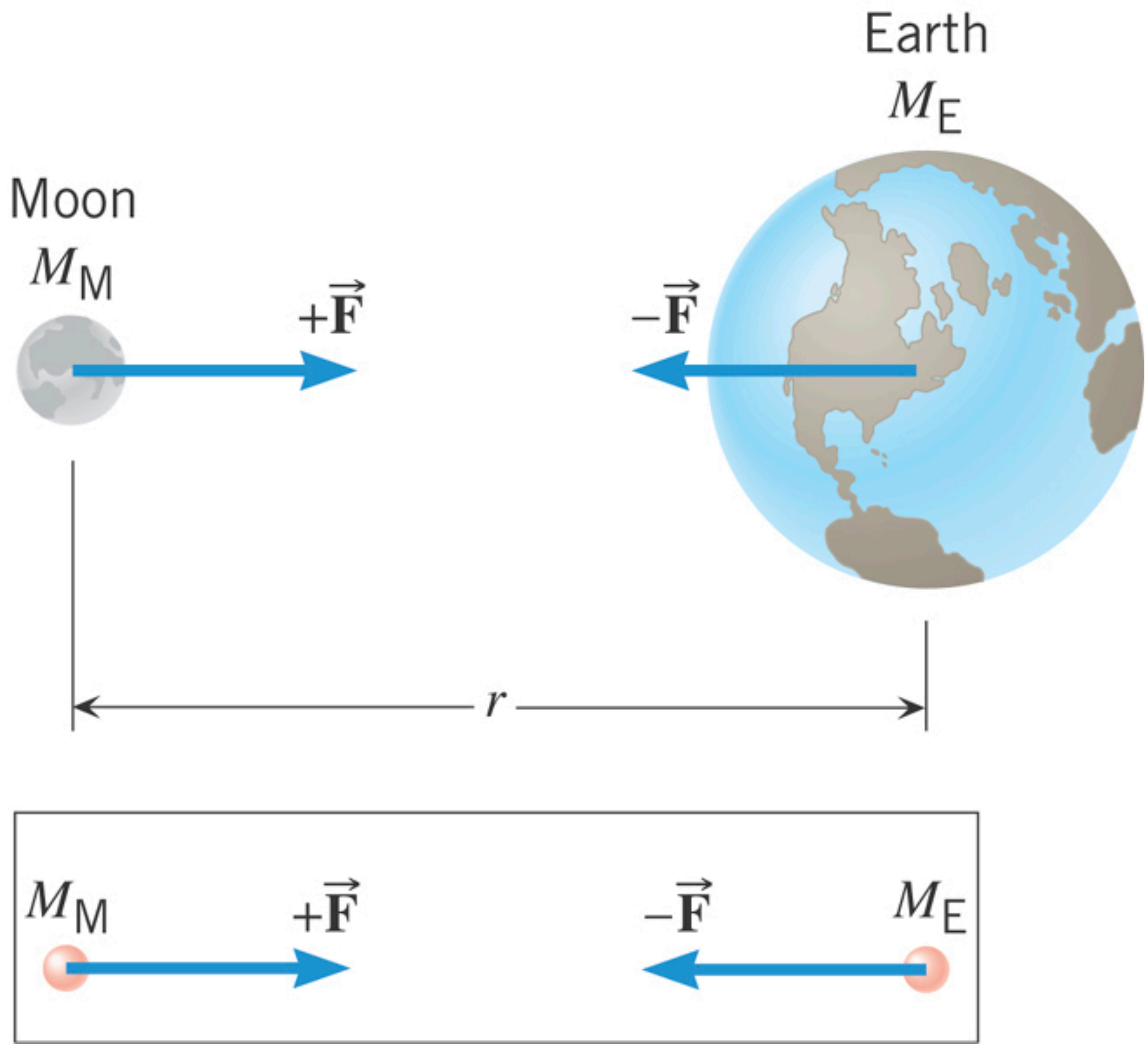


$$F = G\frac{m_1 m_2}{r^2}$$

$$= \left(6.67\times10^{-11}\ \mathrm{N}\cdot\mathrm{m}^2/\mathrm{kg}^2\right)\frac{(12\ \mathrm{kg})(25\ \mathrm{kg})}{(1.2\ \mathrm{m})^2}$$

$$= 1.4\times10^{-8}\ \mathrm{N}$$

4.7 The Gravitational Force



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)

4.7 The Gravitational Force

Relation Between Mass and Weight

WEIGHT is a force vector

$$\vec{\mathbf{W}} = G\frac{mM_E}{r^2},\ \text{downward}$$

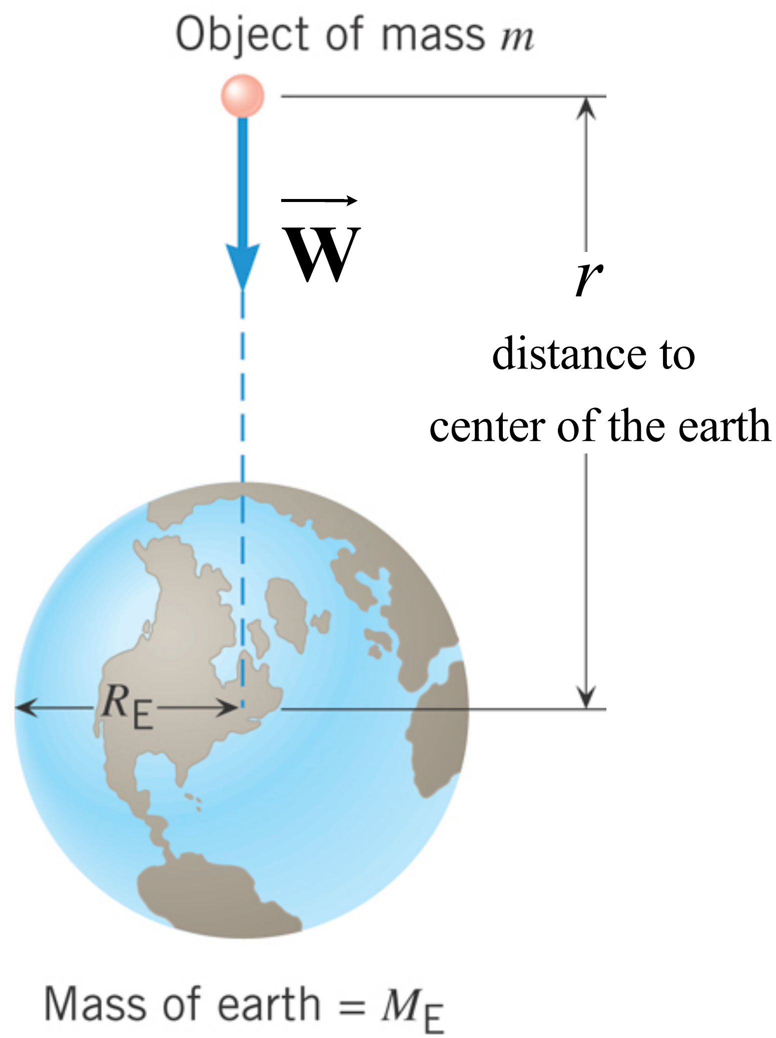
WEIGHT(magnitude) of mass m

$$W = mg, \qquad g = G\frac{M_E}{r^2}$$

Your WEIGHT

WEIGHT DEFINITION

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



Near the earth's surface

$$\boxed{r = R_{\mathrm{E}} = 6.38 \times 10^{6}\ \mathrm{m}}$$

Radius of the earth

$$g = G\frac{M_{\mathrm{E}}}{R_{\mathrm{E}}^{2}}$$

$$= \left(6.67 \times 10^{-11}\,\mathrm{N} \cdot \mathrm{m}^{2}/\mathrm{kg}^{2}\right)\frac{\left(5.98 \times 10^{24}\ \mathrm{kg}\right)}{\left(6.38 \times 10^{6}\ \mathrm{m}\right)^{2}}$$

$$= 9.80\ \mathrm{m/s^{2}}$$

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

Your WEIGHT on the earth

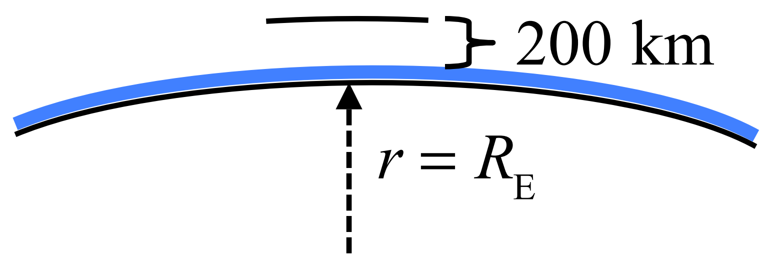
$$W = mg$$

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

$$W = mg = 784\,\mathrm{N}$$

Near the earth's surface

In orbit at altitude = 200 km



$$\boxed{g = 9.80\ \mathrm{m/s^2}}$$

At radius of the earth

At 200 km above the earth

$$r' = R_{\mathrm{E}} + 200\ \mathrm{km} = \underline{6.38\times10^{6}} + 0.2\times10^{6}\ \mathrm{m}$$

$$= \underline{6.58\times10^{6}\ \mathrm{m}}$$

$$\boxed{g' = 9.20\ \mathrm{m/s^2}}$$

$$g' = \frac{GM_{\mathrm{E}}}{r'^{2}} = 9.20\ \mathrm{m/s^2}$$

In low-earth orbit,
your weight is almost the same as on earth. NOT ZERO!

Clicker Question 4.9

A person weighs 500 N on the earth. Consider this person on planet P where the acceleration due to gravity is, g_P = 4.9 m/s^2. Chose the answer that is *false* or answer e).

a) On the earth, the mass of the person is 51 kg.

b) Everywhere on the earth, the person has a mass of 51 kg.

c) On the planet P, the mass of the person is 51 kg.

d) On the planet P, the weight of the person is 250 N.

e) All of the above are true.

Clicker Question 4.9

A person weighs 500 N on the earth. Consider this person on planet P where the acceleration due to gravity is, g_P = 4.9 m/s^2. Chose the answer (if any) that is *false*.

a) On the earth, the <u>mass</u> of the person is 51 kg. $\boxed{m = W/g = 51\ \text{kg}}$

b) Everywhere on the earth, the person has a <u>mass</u> of 51 kg. $\boxed{\text{True}}$

c) On the planet P, the <u>mass</u> of the person is 51 kg. $\boxed{\text{True}}$

d) On the planet P, the <u>weight</u> of the person is 250 N. $\boxed{\begin{aligned} W &= mg_P \\ &= 250\ \text{N} \end{aligned}}$

e) All of the above are true.

4.7 The Gravitational Force

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

4.7 The Gravitational Force

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!

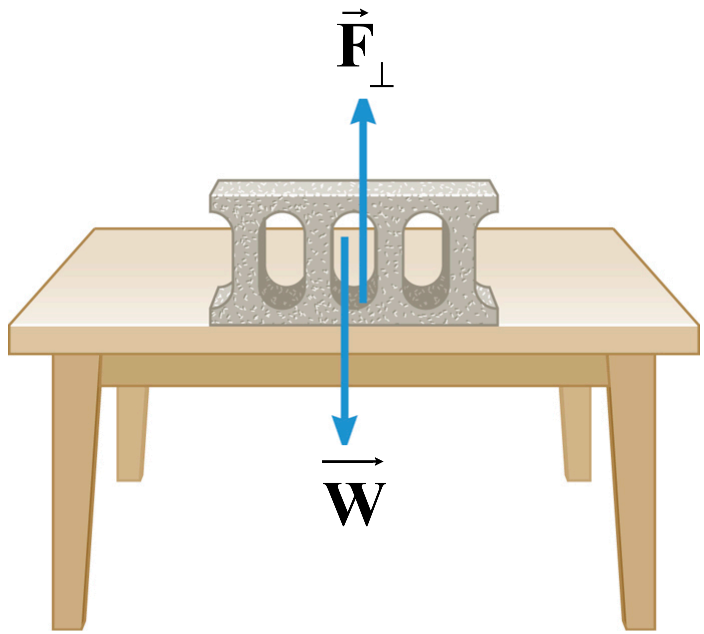
Standing on the ground, the ground also pushes up on the bottom of your feet. Newton's 3rd law!

While falling, the earth pulls on you and you pull on the earth. Gravity requires no contact. YOU CANNOT FEEL GRAVITY.

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 $\vec{\mathbf{F}}_{\mathrm{N}}$



4.8 The Normal Force

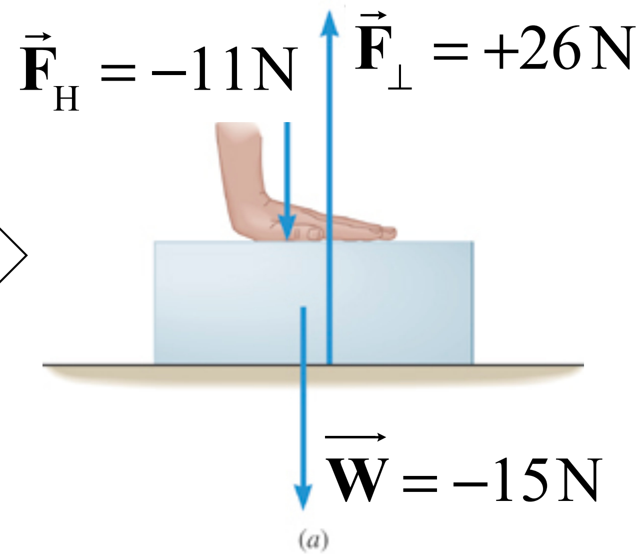
$\vec{\mathbf{F}}_{\perp}$: Normal (or perpendicular) force

$\vec{F}_{\perp}$ is the magnitude

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

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

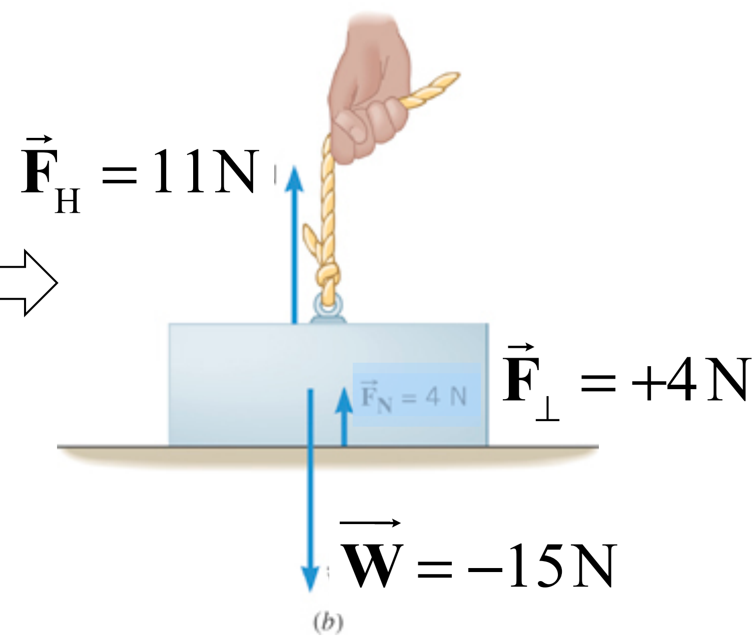
$$\mathbf{F}_{\perp} = +26\text{ N}$$



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

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

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



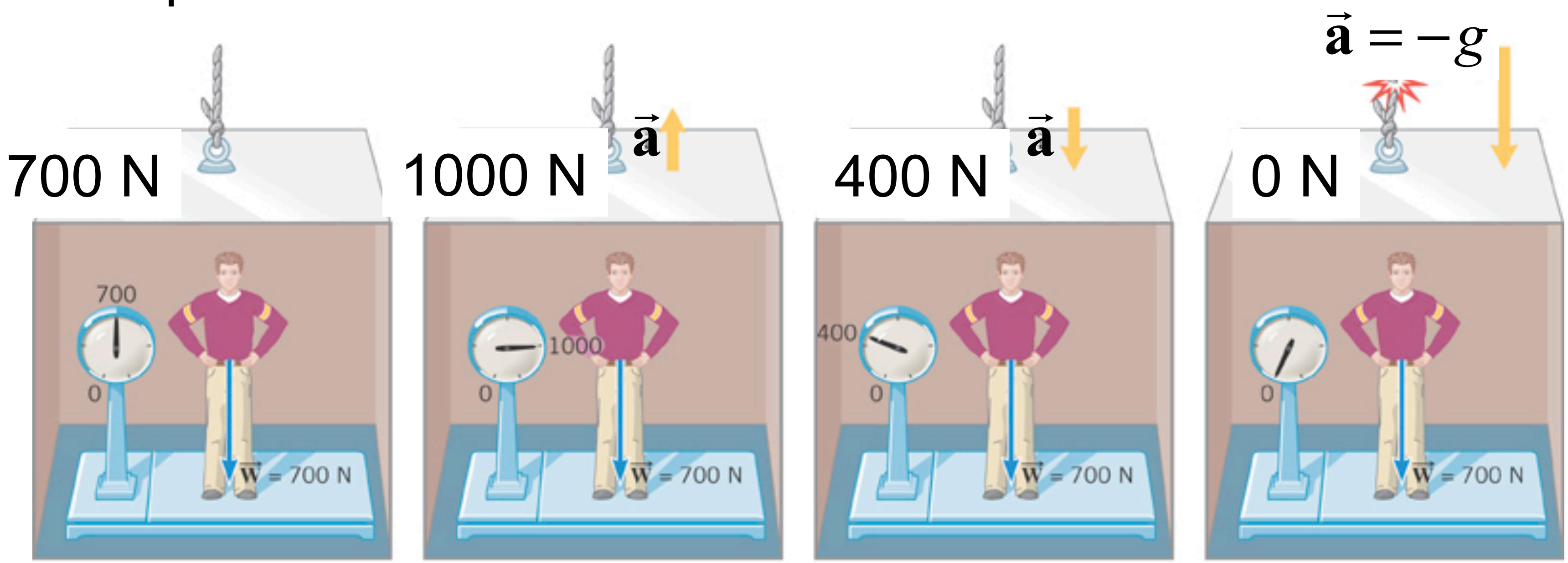
Apparent Weight = Normal force acting on an object

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.

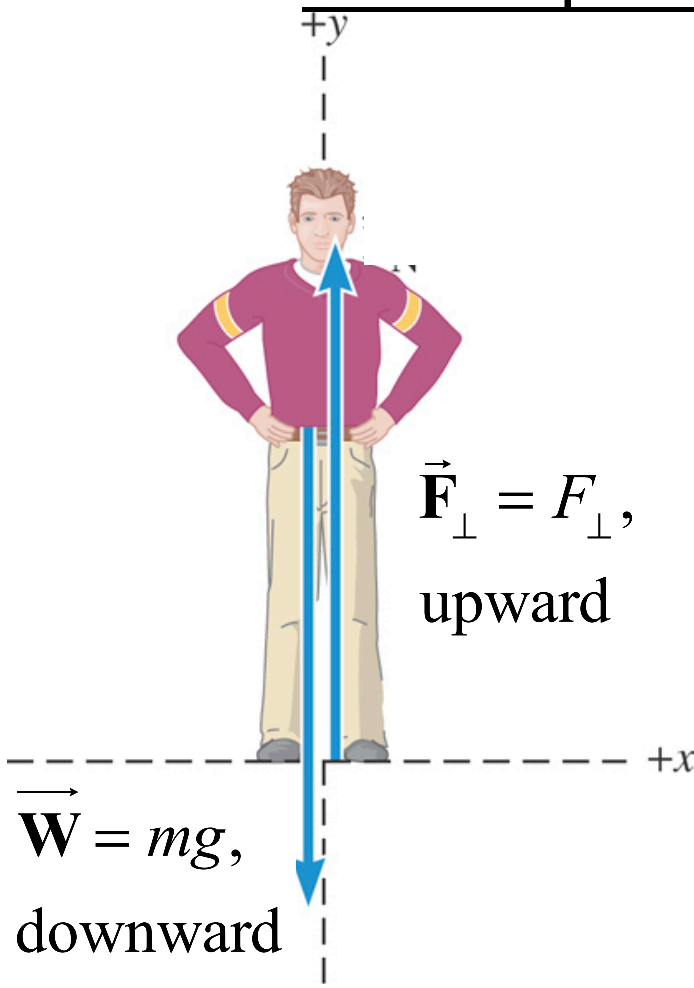
Also, by Newton's 3rd law

It is equal to the normal force the man exerts on the scale.



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

For the person being accelerated (a)



$$\sum F_y = \vec{\mathbf{F}}_\perp + \vec{\mathbf{W}}; \quad \sum F_y = ma$$

$$\vec{\mathbf{F}}_\perp + \vec{\mathbf{W}} = ma$$

$$+F_\perp + (-mg) = ma$$

$$F_\perp = mg + ma$$

apparent weight

true weight

a upward: apparent weight > true weight

a downward: apparent weight < true weight