Pearson Physics Level 20
Unit II Dynamics: Chapter 4
Solutions

Student Book page 197

Concept Check

Diagram (b) best represents the gravitational force acting on the student and on Earth. The diagram shows the force of attraction exerted by the student on Earth and, according to Newton's third law, Earth exerts a force of equal magnitude but opposite direction on the student.

Student Book page 201

Concept Check

(a) From Figure 4.10 on page 201, $g \propto \frac{1}{r^2}$. When r decreases by a factor of 4, the magnitude of the gravitational field strength becomes 16 times its original value.

$$g \propto \frac{1}{\left(\frac{1}{4}r\right)^2}$$
$$\propto 4^2\left(\frac{1}{r^2}\right)$$
$$\propto 16\left(\frac{1}{r^2}\right)$$

(b) When r increases by a factor of 2, the magnitude of the gravitational field strength becomes $\frac{1}{4}$ of its original value.

$$g \propto \frac{1}{(2r)^2}$$
$$\propto \left(\frac{1}{2^2}\right)\left(\frac{1}{r^2}\right)$$
$$\propto \left(\frac{1}{4}\right)\left(\frac{1}{r^2}\right)$$

(c) From the equation $\vec{g} = \frac{\vec{F}_g}{m_{test}}$, $g \propto \frac{1}{m_{test}}$. When m_{test} doubles, the magnitude of the gravitational field strength becomes $\frac{1}{2}$ of its original value.

$$g \propto \frac{1}{2m_{test}}$$
$$\propto \left(\frac{1}{2}\right)\left(\frac{1}{m_{test}}\right)$$

(d) When m_{test} is halved, the magnitude of the gravitational field strength doubles.

$$g \propto \frac{1}{\left(\frac{1}{2}m_{\text{test}}\right)}$$

$$\propto 2\left(\frac{1}{m_{\text{test}}}\right)$$

Student Book page 202

4.1 Check and Reflect

Knowledge

1. Mass is a property of an object that does not depend on location. Weight is the gravitational force that a celestial body exerts on an object, and depends on location. Mass is a scalar quantity, while weight is a vector quantity.

2. Although the inertial mass and gravitational mass of an object are numerically the same, the masses differ in how they are measured.

Inertial mass is measured by finding the ratio of a known net force acting on an object to its acceleration, $m = \frac{F_{\text{net}}}{a}$ where both $\vec{F}_{\text{net}}$ and $\vec{a}$ act in the same direction.

Gravitational mass is measured by comparing the gravitational force acting on standard masses with the gravitational force acting on the object. If the two forces are equal, the mass of the object is equal to the numerical value of the standard masses.

In order to measure gravitational mass, a measurable gravitational field must be present. In deep space where no gravitational fields are detectable, the gravitational mass of an object cannot be measured. However, its inertial mass can be measured.

3. Gravitational acceleration ($\vec{g}$) is the acceleration of an object while free falling in a vacuum, and is directed toward the centre of a celestial body. Gravitational acceleration has units of metres per second squared (m/s^2) and is determined using the equation $\vec{g} = \frac{\vec{F}_{\text{net}}}{m}$. Near or on Earth's surface, the gravitational acceleration is about 9.81 m/s^2 [toward Earth's centre].

Gravitational field strength ($\vec{g}$) is the ratio of the force of gravity acting on an object to its mass. Gravitational field strength has units of newtons per kilogram (N/kg) and is determined using the equation $\vec{g} = \frac{\vec{F}_{\text{g}}}{m}$. Near or on Earth's surface, the gravitational field strength is about 9.81 N/kg [toward Earth's centre].

At a given location near a celestial body, the magnitude of the gravitational acceleration is numerically equivalent to the magnitude of the gravitational field strength.

4. The concept of a gravitational field suggests that a mass influences the three-dimensional space around it, and it is this region of influence that affects all other masses. So the objects do not interact directly with each other, but through a region of influence.

5. Physicists use the concept of a field to describe gravity because the three-dimensional nature of fields shows more clearly that there is a continuum of gravitational force that extends out to infinity in three-dimensions around a mass. The field model suggests that forces are transmitted outward in three-dimensions at a certain speed, whereas the action-at-a-distance model suggests that forces are transmitted instantly over any distance.

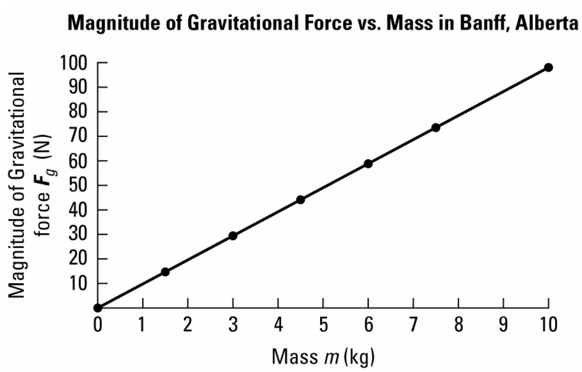
6. In a vacuum, there is no air resistance acting on an object in free fall. So the time it takes an object to fall depends only on the gravitational field strength and the height, not on its mass. So the feather and bowling ball will take the same length of time to fall from a given height.

Applications

7. On a balance, the object experiences the same gravitational field strength as the standard masses do. So it does not matter on which celestial body you measure the gravitational mass because the effect of the gravitational field strength cancels out.

8. Gravitational mass cannot be measured in deep space where no gravitational field can be measured, unless an artificial gravity is created by rotating a spaceship. However, the inertial mass of an object can be easily measured by applying a known net force and measuring the acceleration of the object.

9. (a)



(b) The slope of the line is 9.80 N/kg.

(c) The slope represents the magnitude of the gravitational field strength in Banff, Alberta.

10. A 5.0-kg medicine ball would be harder to accelerate than a basketball in space since the inertial mass of the medicine ball is greater than that of the basketball.

Extensions

11. This is an excellent opportunity to motivate students interested in fitness and/or athletics, especially those interested in weightlifting. It is also a good opportunity for a field-trip to a local gymnasium. Encourage a small group of students to visit the facility and videotape the use of dumbbells, barbells, and elastic springs. Students should prepare a presentation based on their findings for their peers.

12. Some occupations that require a knowledge of gravitational field strength are aeronautical engineers, bungee jumping operators, designers of amusement park rides, air force personnel, pilots, geophysicists, geologists, and environmental engineers.

When geophysicists and geologists search for deposits of minerals, oil, and natural gas, they use sensitive devices called gravimeters and apply their understanding of gravitational field strength to interpret the data. Gravimeters are also used in earthquake research to detect the motion of the tectonic plates in Earth's crust.

Environmental engineers use gravimeters to monitor the water table in deep aquifers and the increase in global sea levels due to global warming.

Any scientist involved in the space program or in the manufacture of space-related equipment, such as the Canadarm, requires a knowledge of gravitational field strength.

13.

	Gravitational Mass	**Inertial Mass**	**Gravitational Force**
Definition	A comparison of the gravitational force on an object to the gravitational force on standard masses	The ratio of a known net force acting on an object to the acceleration of the object	The force exerted by a celestial body on an object or the force of attraction exerted by one object on another
SI Unit	kg	kg	N
Measuring Instrument(s)	equal arm balance	spring scale calibrated in newtons and an accelerometer	spring scale calibrated in newtons
How the Quantity Is Measured	Place the object on one pan and add standard masses to the other until both pans balance. Determine the value of the standard masses.	Accelerate the object with a known net force, and determine its acceleration. Calculate the ratio of the net force to acceleration.	Hook the object to a spring scale. Read the force on the spring scale.
Factors It Depends On	object in question	object in question	gravitational field strength at the location of the object, and the mass of the object
Variability with Location	constant	constant	varies

Student Book page 205

Concept Check

From Newton's law of gravitation, $F_g \propto m_A m_B$ and $F_g \propto \frac{1}{r^2}$.

(a) When the mass of each ball doubles, the magnitude of the gravitational force quadruples.

$$F_g \propto (2m_A)(2m_B)$$
$$\propto (2)(2)m_A m_B$$
$$\propto 4m_A m_B$$

(b) When r is halved, the magnitude of the gravitational force quadruples.

$$F_g \propto \frac{1}{\left(\frac{1}{2}r\right)^2}$$
$$\propto 2^2\left(\frac{1}{r^2}\right)$$
$$\propto 4\left(\frac{1}{r^2}\right)$$

(c) When the mass of each ball is halved and r doubles, the magnitude of the gravitational force becomes $\frac{1}{16}$ of its original value.

$$F_g \propto \left(\frac{1}{2}m_A\right)\left(\frac{1}{2}m_B\right)$$
$$\propto \left(\frac{1}{2}\right)\left(\frac{1}{2}\right)m_A m_B$$
$$\propto \left(\frac{1}{4}\right)m_A m_B$$

and

$$F_g \propto \frac{1}{(2r)^2}$$
$$\propto \left(\frac{1}{2^2}\right)\left(\frac{1}{r^2}\right)$$
$$\propto \left(\frac{1}{4}\right)\left(\frac{1}{r^2}\right)$$

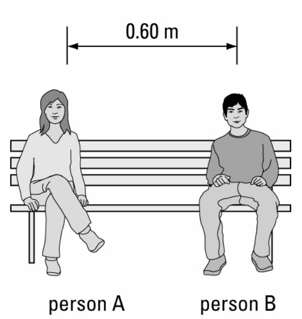
So the factor change of F_g is $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$.

Student Book page 207

Example 4.1 Practice Problems

1. ***Given***

$m_A = 55$ kg
$m_B = 80$ kg
$r = 0.60$ m



Required

magnitude of gravitational force exerted by B on A (F_g)

Analysis and Solution

Calculate F_g using Newton's law of gravitation.

$$F_g = \frac{Gm_A m_B}{r^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\cancel{\text{kg}^2}}\right)(55\ \cancel{\text{kg}})(80\ \cancel{\text{kg}})}{(0.60\ \text{m})^2}$$

$$= 8.2\times10^{-7}\ \text{N}$$

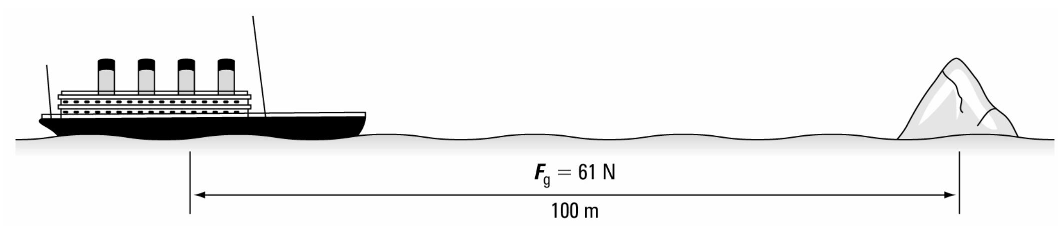
Paraphrase

The magnitude of the gravitational force exerted by person B on person A is 8.2×10^{-7} N.

2. ***Given***

$m_T = 4.6\times10^7$ kg

$F_g = 61$ N $\qquad r = 100$ m



Required

mass of the iceberg (m_i)

Analysis and Solution

Calculate m_i using Newton's law of gravitation.

$$F_g = \frac{Gm_T m_i}{r^2}$$

$$m_i = \frac{F_g r^2}{Gm_T}$$

$$= \frac{(61\ \text{N})(100\ \text{m})^2}{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\cancel{2}}}\right)(4.6\times10^7\ \cancel{\text{kg}})}$$

$$= 2.0\times10^8\ \text{kg}$$

Paraphrase

The mass of the iceberg was 2.0×10^8 kg.

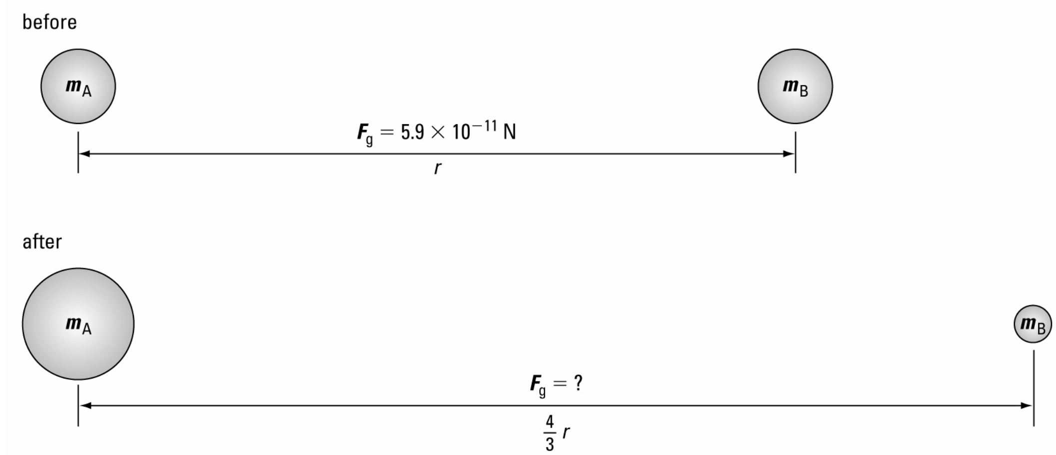
Student Book page 208

Example 4.2 Practice Problem

1. (a) ***Analysis and Solution***

From Newton's law of gravitation, $F_g \propto m_A m_B$ and $F_g \propto \frac{1}{r^2}$.

The figure below represents the situation of the problem.



$$F_g \propto \left(\frac{3}{2}m_A\right)\left(\frac{1}{2}m_B\right) \quad \text{and} \quad F_g \propto \frac{1}{\left(\frac{4}{3}r\right)^2}$$

$$\propto \left(\frac{3}{2}\right)\left(\frac{1}{2}\right) m_A m_B \qquad \propto \left(\frac{3}{4}\right)^2 \left(\frac{1}{r^2}\right)$$

$$\propto \left(\frac{3}{4}\right) m_A m_B \qquad \propto \left(\frac{9}{16}\right)\left(\frac{1}{r^2}\right)$$

Calculate the factor change of F_g.

$$\frac{3}{4} \times \frac{9}{16} = \frac{27}{64}$$

Calculate F_g.

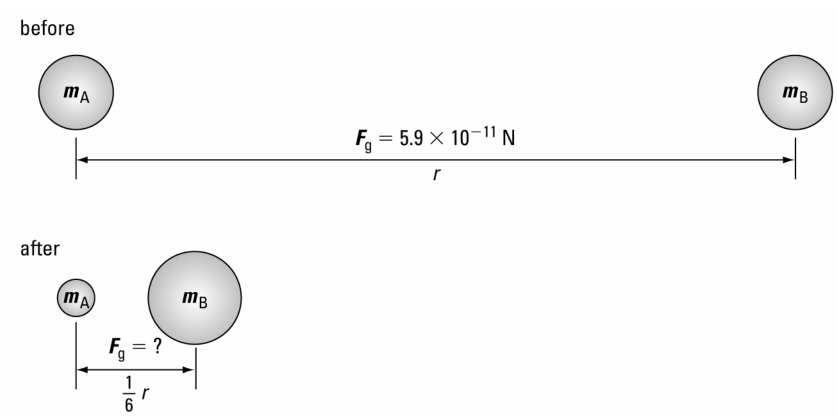
$$\frac{27}{64} F_g = \frac{27}{64} \times (5.9 \times 10^{-11} \text{ N})$$
$$= 2.5 \times 10^{-11} \text{ N}$$

The new magnitude of the gravitational force will be 2.5×10^{-11} N.

(b) ***Analysis and Solution***

From Newton's law of gravitation, $F_g \propto m_A m_B$ and $F_g \propto \frac{1}{r^2}$.

The figure below represents the situation of the problem.



$$F_g \propto \left(\frac{1}{2}m_A\right)\left(\frac{5}{4}m_B\right) \quad \text{and} \quad F_g \propto \frac{1}{\left(\frac{1}{6}r\right)^2}$$

$$\propto \left(\frac{1}{2}\right)\left(\frac{5}{4}\right) m_A m_B \qquad \propto 6^2\left(\frac{1}{r^2}\right)$$

$$\propto \left(\frac{5}{8}\right) m_A m_B \qquad \propto 36\left(\frac{1}{r^2}\right)$$

Calculate the factor change of F_g.

$$\frac{5}{8} \times 36 = \frac{45}{2}$$

Calculate F_g.

$$\frac{45}{2} F_g = \frac{45}{2} \times (5.9 \times 10^{-11}\ \text{N})$$
$$= 1.3 \times 10^{-9}\ \text{N}$$

The new magnitude of the gravitational force will be 1.3×10^{-9} N.

Student Book page 209

Example 4.3 Practice Problems

1. ***Given***

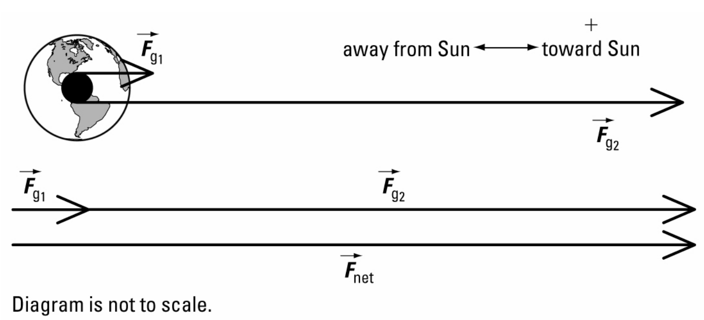
$m_{Earth} = 5.97 \times 10^{24}$ kg
$m_{Moon} = 7.35 \times 10^{22}$ kg
$m_{Sun} = 1.99 \times 10^{30}$ kg
$r_{E\ to\ M} = 3.84 \times 10^{8}$ m
$r_{E\ to\ S} = 1.50 \times 10^{11}$ m

Required

net gravitational force on Earth ($\vec{F}_{g_{net}}$)

Analysis and Solution

Draw a free-body diagram for Earth.



Calculate F_g exerted by the Moon on Earth using Newton's law of gravitation.

$$(F_g)_1 = \frac{Gm_{Earth}m_{Moon}}{(r_{E\ to\ M})^2}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}\right)(5.97 \times 10^{24}\ kg)(7.35 \times 10^{22}\ kg)}{(3.84 \times 10^8\ m)^2}$$

$= 1.985 \times 10^{20}$ N

$\vec{F}_{g_1} = 1.985 \times 10^{20}$ N [toward Moon's centre]

Calculate F_g exerted by the Sun on Earth using Newton's law of gravitation.

$$(F_g)_2 = \frac{Gm_{Earth}m_{Sun}}{(r_{E\ to\ S})^2}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}\right)(5.97 \times 10^{24}\ kg)(1.99 \times 10^{30}\ kg)}{(1.50 \times 10^{11}\ m)^2}$$

$= 3.522 \times 10^{22}$ N

$\vec{F}_{g_2} = 3.522 \times 10^{22}$ N [toward Sun's centre]

Find the net gravitational force on Earth using the vector addition diagram.

$\vec{F}_{g_{net}} = \vec{F}_{g_1} + \vec{F}_{g_2}$

$F_{g_{net}} = F_{g_1} + F_{g_2}$

$= 1.985 \times 10^{20}$ N $+ 3.522 \times 10^{22}$ N

$= 3.54 \times 10^{22}$ N

$\vec{F}_{g_{net}} = 3.54 \times 10^{22}$ N [toward Sun's centre]

Paraphrase

The net gravitational force on Earth due to the Sun and Moon during a solar eclipse is 3.54×10^{22} N [toward Sun's centre].

2. ***Given***

$m_{Earth} = 5.97 \times 10^{24}$ kg

$m_{Moon} = 7.35 \times 10^{22}$ kg

$m_{Sun} = 1.99 \times 10^{30}$ kg

$r_{E\ to\ M} = 3.84 \times 10^8$ m

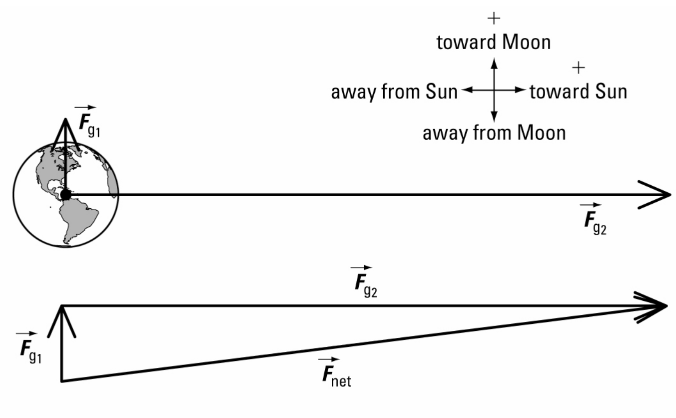
$r_{E\ to\ S} = 1.50 \times 10^{11}$ m

Required

net gravitational force on Earth ($\vec{F}_{g_{net}}$)

Analysis and Solution

Draw a free-body diagram for Earth.



Calculate F_g exerted by the Moon on Earth using Newton's law of gravitation.

$$(F_g)_1 = \frac{Gm_{Earth}m_{Moon}}{(r_{E\ to\ M})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{N\bullet m^2}{\cancel{kg^2}}\right)(5.97\times10^{24}\ \cancel{kg})(7.35\times10^{22}\ \cancel{kg})}{(3.84\times10^{8}\ m)^2}$$

$$= 1.985\times10^{20}\ N$$

$$\vec{F}_{g_1} = 1.985\times10^{20}\ N\ [\text{toward Moon's centre}]$$

Calculate F_g exerted by the Sun on Earth using Newton's law of gravitation.

$$(F_g)_2 = \frac{Gm_{Earth}m_{Sun}}{(r_{E\ to\ S})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{N\bullet m^2}{\cancel{kg^2}}\right)(5.97\times10^{24}\ \cancel{kg})(1.99\times10^{30}\ \cancel{kg})}{(1.50\times10^{11}\ m)^2}$$

$$= 3.522\times10^{22}\ N$$

$$\vec{F}_{g_2} = 3.522\times10^{22}\ N\ [\text{toward Sun's centre}]$$

Find the net gravitational force on Earth.

$$\vec{F}_{g_{net}} = \vec{F}_{g_1} + \vec{F}_{g_2}$$

From the vector addition diagram, $F_{net_x} = F_{g_2}$ and $F_{net_y} = F_{g_1}$.

Use the Pythagorean theorem to find the magnitude of $\vec{F}_{g_{net}}$.

$$F_{g_{net}} = \sqrt{\left(F_{net_x}\right)^2 + \left(F_{net_y}\right)^2}$$

$$= \sqrt{\left(F_{g_2}\right)^2 + \left(F_{g_1}\right)^2}$$

$$= \sqrt{(3.522\times10^{22}\ N)^2 + (1.985\times10^{20}\ N)^2}$$

$$= 3.52\times10^{22}\ N$$

Use the tangent function to find the direction of $\vec{F}_{g_{net}}$.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$
$$= \frac{1.985\times10^{20}\ \cancel{N}}{3.522\times10^{22}\ \cancel{N}}$$
$$= 0.005636$$
$$\theta = \tan^{-1}(0.005636)$$
$$= 0.3°$$

From the vector addition diagram, this angle is between $\vec{F}_{g_{net}}$ and $\vec{F}_{g_2}$, which is the same as the angle between $\vec{F}_{g_{net}}$ and the positive x-axis.

$$\vec{F}_{g_{net}} = 3.52\times10^{22}\ \text{N}\ [0.3°]$$

Paraphrase

The net gravitational force on Earth due to the Sun and Moon during the third quarter phase of the Moon is 3.52×10^{22} N [0.3°].

Student Book page 212

Example 4.4 Practice Problem

1. (a) ***Given***

$m_w = 1.0000$ kg

$m_{Earth} = 5.9742 \times 10^{24}$ kg

$m_{Moon} = 7.3483 \times 10^{22}$ kg

$r_{E\ to\ M} = 3.8440 \times 10^8$ m

$G = 6.67259 \times 10^{-11}$ N•m^2/kg^2

$r_{Earth} = 6.3781 \times 10^6$ m

$r_{Moon} = 1.7374 \times 10^6$ m

Required

gravitational force exerted by the Moon on the water ($\vec{F}_g$)

Analysis and Solution

At the midpoint of A and B, the water is located at Earth's centre.

So $r = r_{E\ to\ M}$

$= 3.8440 \times 10^8$ m

Calculate F_g exerted by the Moon on the water using Newton's law of gravitation.

$$F_g = \frac{Gm_w m_{Moon}}{r^2}$$
$$= \frac{\left(6.67259\times10^{-11}\ \frac{\text{N•m}^2}{\cancel{\text{kg}^2}}\right)(1.0000\ \cancel{\text{kg}})(7.3483\times10^{22}\ \cancel{\text{kg}})}{(3.8440\times10^{8}\ \text{m})^2}$$
$$= 3.3183\times10^{-5}\ \text{N}$$
$$\vec{F}_g = 3.3183\times10^{-5}\ \text{N [toward Moon's centre]}$$

Paraphrase

The gravitational force exerted by the Moon on the water at the midpoint of A and B is 3.3183×10^{-5} N [toward Moon's centre].

(b) *Given*

m_w = 1.0000 kg

m_{Earth} = 5.9742 × 10^{24} kg r_{Earth} = 6.3781 × 10^6 m

m_{Moon} = 7.3483 × 10^{22} kg r_{Moon} = 1.7374 × 10^6 m

$r_{E\ to\ M}$ = 3.8440 × 10^8 m

G = 6.67259 × 10^{-11} N•m²/kg²

Required

gravitational force exerted by the Moon on the water ($\vec{F}_g$)

Analysis and Solution

Find the separation distance between the water and the Moon.

$$\begin{aligned} r &= r_{E\ to\ M} + r_{Earth} \\ &= 3.8440 \times 10^8 \text{ m} + 6.3781 \times 10^6 \text{ m} \\ &= 3.907\ 78 \times 10^8 \text{ m} \end{aligned}$$

Calculate F_g exerted by the Moon on the water using Newton's law of gravitation.

$$\begin{aligned} F_g &= \frac{Gm_w m_{Moon}}{r^2} \\ &= \frac{\left(6.67259 \times 10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\cancel{\text{kg}^2}}\right)(1.0000\ \cancel{\text{kg}})(7.3483 \times 10^{22}\ \cancel{\text{kg}})}{(3.907\ 78 \times 10^8\ \text{m})^2} \\ &= 3.2109 \times 10^{-5} \text{ N} \\ \vec{F}_g &= 3.2109 \times 10^{-5} \text{ N [toward Moon's centre]} \end{aligned}$$

Paraphrase

The gravitational force exerted by the Moon on the water at B is 3.2109 × 10^{-5} N [toward Moon's centre].

Student Book page 215

4.2 Check and Reflect

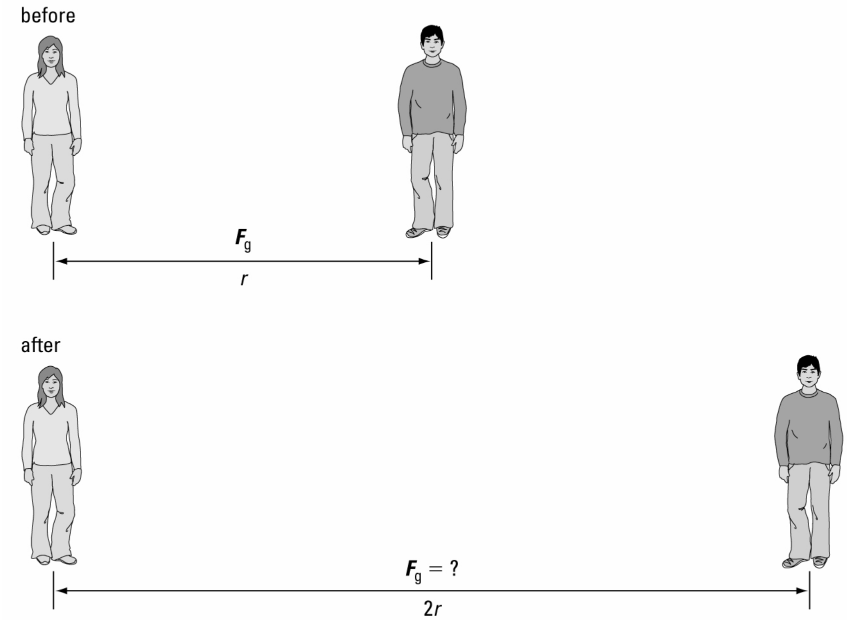
Knowledge

1. The gravitational constant G is called a "universal" constant because it is considered to be the same value everywhere in the universe.

2. A torsion balance is a device that has two spheres, each of mass m, attached to the ends of a light rod, and another two spheres, each of mass M, attached to the ends of another light rod. When spheres M are brought close to spheres m, the gravitational force exerted by M on m causes the rod connecting spheres m to rotate horizontally toward M. This rotation, in turn, twists the fibre and mirror assembly attached to the rod connecting spheres m. The gravitational force is related to the angle of rotation. Since the values of m and M, the separation distance between each pair of spheres, and the amount of deflection can be measured, the gravitational force can be calculated. Using these values, it is possible to calculate the value of the universal gravitational constant using Newton's law of gravitation, $G = \frac{F_g r^2}{mM}$.

3. From Newton's law of gravitation, $F_g \propto m_A m_B$ and $F_g \propto \frac{1}{r^2}$.

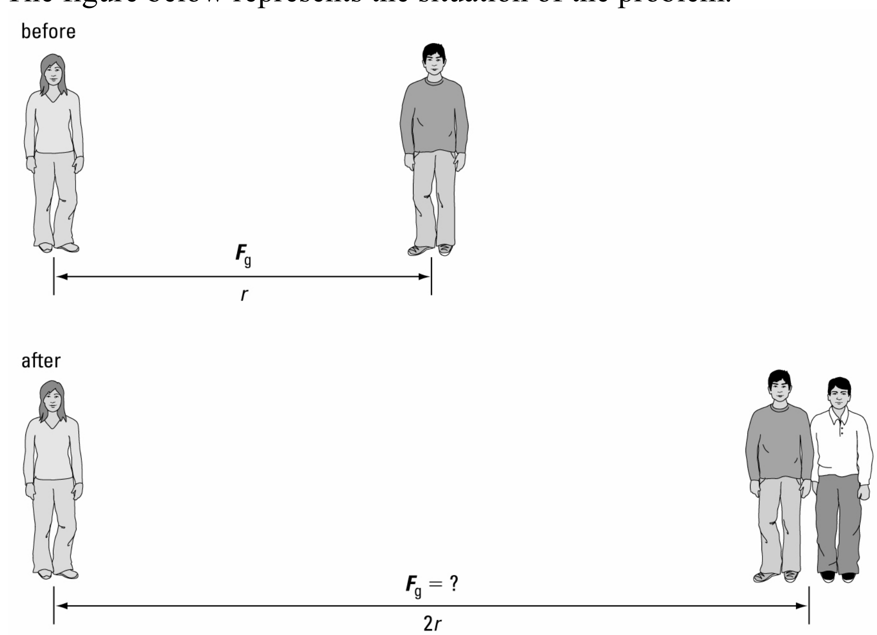
(a) The figure below represents the situation of the problem.



When r doubles, the magnitude of the gravitational force becomes $\frac{1}{4}$ of its original value.

$$\begin{aligned} F_g &\propto \frac{1}{(2r)^2} \\ &\propto \left(\frac{1}{2^2}\right)\left(\frac{1}{r^2}\right) \\ &\propto \left(\frac{1}{4}\right)\left(\frac{1}{r^2}\right) \end{aligned}$$

(b) The figure below represents the situation of the problem.



When r doubles and one mass also doubles, the magnitude of the gravitational force becomes $\frac{1}{2}$ of its original value.

$$F_g \propto \frac{1}{(2r)^2} \propto \left(\frac{1}{2^2}\right)\left(\frac{1}{r^2}\right) \propto \left(\frac{1}{4}\right)\left(\frac{1}{r^2}\right) \quad \text{and} \quad F_g \propto (m_A)(2m_B) \propto 2m_Am_B$$

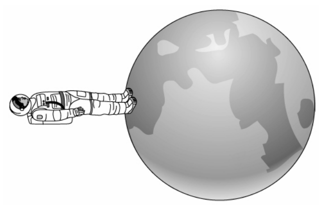
So the factor change of F_g is $\frac{1}{4} \times 2 = \frac{1}{2}$.

Applications

4. (a) (i) *Given*

$m_a = 100$ kg

$m_{Moon} = 7.35 \times 10^{22}$ kg $\qquad r_{Moon} = 1.74 \times 10^6$ m



Required

magnitude of gravitational force exerted by the Moon on the astronaut (F_g)

Analysis and Solution

Calculate F_g using Newton's law of gravitation.

$$F_g = \frac{Gm_am_{Moon}}{(r_{Moon})^2} = \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}\right)(100\ \text{kg})(7.35\times10^{22}\ \text{kg})}{(1.74\times10^6\ \text{m})^2} = 162\ \text{N}$$

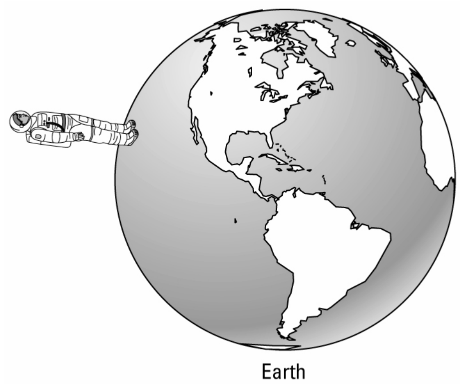
Paraphrase

The magnitude of the gravitational force exerted by the Moon on the astronaut is 162 N.

(ii) *Given*

$m_a = 100$ kg

$m_{Earth} = 5.97 \times 10^{24}$ kg $\qquad r_{Earth} = 6.38 \times 10^6$ m



Required
magnitude of gravitational force exerted by Earth on the astronaut (F_g)
Analysis and Solution
Calculate F_g using Newton's law of gravitation.

$$F_g = \frac{Gm_a m_{Earth}}{(r_{Earth})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{N\bullet m^2}{\cancel{kg^2}}\right)(100\ \cancel{kg})(5.97\times10^{24}\ \cancel{kg})}{(6.38\times10^6\ m)^2}$$

$$= 978\ N$$

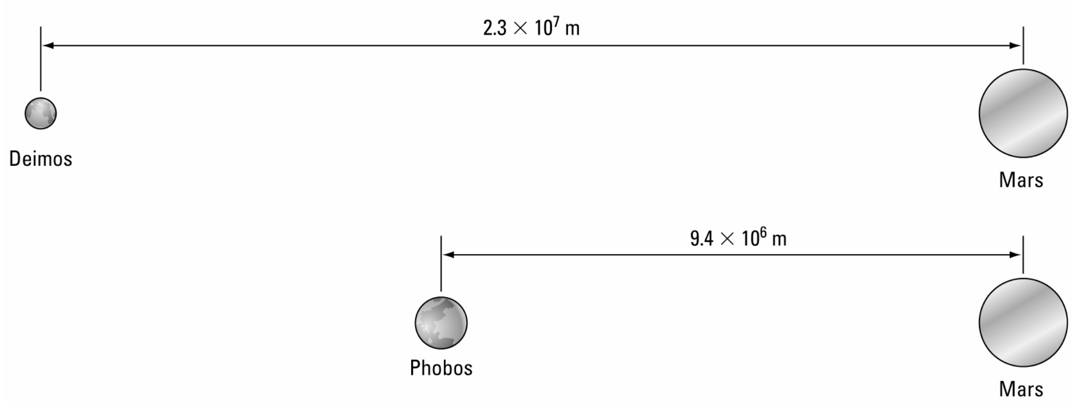
Paraphrase
The magnitude of the gravitational force exerted by Earth on the astronaut is 978 N.

(b) The values of F_g are different because Earth is about 81 times more massive than the Moon and Earth's radius is about 3.7 times that of the Moon. The combined effect of mass and separation distance makes F_g about 6 times greater on Earth than on the Moon.

5. (a) From Newton's law of gravitation, $F_g \propto m_A m_B$ and $F_g \propto \frac{1}{r^2}$. Phobos is about 10 times more massive than Deimos, and about 2 times closer to Mars than Deimos. Combining both these factors, Phobos should exert a greater gravitational force on Mars than Deimos.

(b) ***Given***

$m_D = 1.8 \times 10^{15}$ kg
$m_P = 1.1 \times 10^{16}$ kg
$m_{Mars} = 6.42 \times 10^{23}$ kg
$r_{D\ to\ M} = 2.3 \times 10^7$ m
$r_{P\ to\ M} = 9.4 \times 10^6$ m



Required
magnitude of gravitational force exerted by Deimos and Phobos on Mars (F_g)
Analysis and Solution
Calculate F_g for each moon using Newton's law of gravitation.
Deimos

$$F_g = \frac{Gm_D m_{Mars}}{(r_{D\ to\ M})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{N\bullet m^2}{\cancel{kg^2}}\right)(1.8\times10^{15}\ \cancel{kg})(6.42\times10^{23}\ \cancel{kg})}{(2.3\times10^{7}\ m)^2}$$

$= 1.5 \times 10^{14}$ N

Phobos

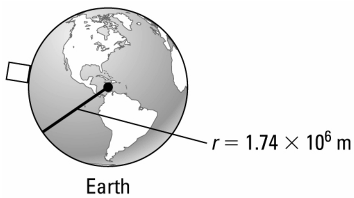
$$F_g = \frac{Gm_P m_{Mars}}{(r_{P\ to\ M})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{N\bullet m^2}{\cancel{kg^2}}\right)(1.1\times10^{16}\ \cancel{kg})(6.42\times10^{23}\ \cancel{kg})}{(9.4\times10^{6}\ m)^2}$$

$= 5.3 \times 10^{15}$ N

Paraphrase
The magnitude of the gravitational force exerted by Deimos on Mars is 1.5×10^{14} N and that by Phobos on Mars is 5.3×10^{15} N. This result agrees with the prediction in part (a).

6. (a) ***Given***
$m = 1.00$ kg $\qquad M = 5.97 \times 10^{24}$ kg
$r = 1.74 \times 10^6$ m



Required
gravitational force exerted by hypothetical Earth on object ($\vec{F}_g$)

Analysis and Solution
Calculate F_g using Newton's law of gravitation.

$$F_g = \frac{GmM}{r^2}$$
$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\cancel{\text{kg}^2}}\right)(1.00\ \cancel{\text{kg}})(5.97 \times 10^{24}\ \cancel{\text{kg}})}{(1.74 \times 10^6\ \text{m})^2}$$
$$= 132\ \text{N}$$
$$\vec{F}_g = 132\ \text{N [toward Earth's centre]}$$

Paraphrase
The gravitational force exerted by the hypothetical Earth on the object is 132 N [toward Earth's centre].

(b) ***Given***
$m = 1.00$ kg $M = 5.97 \times 10^{24}$ kg
$r = 6.38 \times 10^6$ m

Required
gravitational force exerted by Earth on object ($\vec{F}_g$)

Analysis and Solution
Calculate F_g using Newton's law of gravitation.

$$F_g = \frac{GmM}{r^2}$$
$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\cancel{\text{kg}^2}}\right)(1.00\ \cancel{\text{kg}})(5.97 \times 10^{24}\ \cancel{\text{kg}})}{(6.38 \times 10^6\ \text{m})^2}$$
$$= 9.78\ \text{N}$$
$$\vec{F}_g = 9.78\ \text{N [toward Earth's centre]}$$

Paraphrase and Verify
The gravitational force exerted by Earth on the object is 9.78 N [toward Earth's centre]. So the answer in part (a) is about 13.4 times greater than that in part (b).

Extensions

7. (a) The steps needed to solve a problem involving Newton's law of gravitation are
- state the equation,
- substitute the given values for the masses, separation distance, and the universal gravitational constant using appropriate units, and

• perform the correct mathematical operations.
A common error is not squaring the separation distance.

(b) The steps needed to solve a problem involving Newton's law of gravitation using proportionalities are:
• determine the factor change for the masses,
• determine the factor change for the separation distance,
• multiply both factors to get the combined factor change, and
• multiply the given gravitational force by this factor to determine the new gravitational force.
A common error is not squaring the separation distance when determining the factor change.

8. (a) In Newton's day, scientists working alone could not benefit from group wisdom and expertise. Religion influenced the philosophies of many scientists and affected the types of hypotheses and observations they made. Being knowledgeable in many different fields meant that scientists may not have been focussed enough in a given field, and their research may have been scattered.

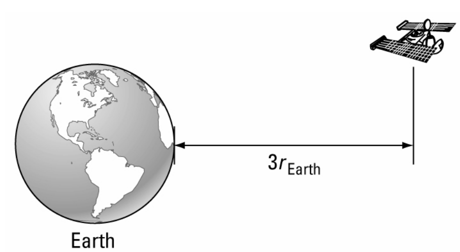
(b) Today, there are likely several scientists around the world researching the same or similar problems. A scientist in Argentina, for example, can contact and share information with another scientist in the Netherlands by phone or e-mail. The scientific community generally separates religion from science, but political and corporate interests are generally not separated from science. There are still many scientific questions that involve ethical decisions, and these decisions are often influenced by religious beliefs. Modern scientists tend to specialize within a particular field and consult with colleagues for information and/or advice, when they require information outside their specialty.

Student Book page 219

Example 4.5 Practice Problems

1. (a) ***Analysis and Solution***
Since the satellite is $3r_{\text{Earth}}$ above Earth, it is $4r_{\text{Earth}}$ from Earth's centre.

(b) ***Given***
$4r_{\text{Earth}}$ from part (a)
$m_{\text{Earth}} = 5.97 \times 10^{24}$ kg $\quad$ $r_{\text{Earth}} = 6.38 \times 10^{6}$ m



Required
magnitude of gravitational acceleration of satellite (g)

Analysis and Solution

Use the equation $g = \frac{GM_{\text{source}}}{r^2}$ to calculate the magnitude of the gravitational acceleration.

$$\begin{aligned} g &= \frac{Gm_{\text{Earth}}}{r^2} \\ &= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not{2}}}\right)(5.97\times10^{24}\ \not{\text{kg}})}{\left[4\left(6.38\times10^{6}\ \text{m}\right)\right]^2} \\ &= 6.11\times10^{-1}\ \text{m/s}^2 \end{aligned}$$

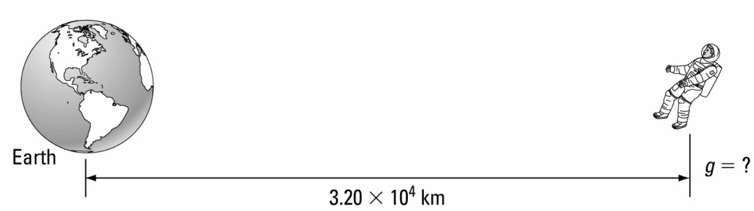
Paraphrase

The magnitude of the gravitational acceleration of the satellite is 6.11×10^{-1} m/s^2.

2. (a) ***Given***

m_a = 80.0 kg r = 3.20×10^4 km or 3.20×10^7 m

m_{Earth} = 5.97×10^{24} kg



Required

magnitude of gravitational field strength at the location of astronaut (g)

Analysis and Solution

Use the equation $g = \frac{GM_{\text{source}}}{r^2}$ to calculate the magnitude of the gravitational field strength.

$$\begin{aligned} g &= \frac{Gm_{\text{Earth}}}{r^2} \\ &= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not{2}}}\right)(5.97\times10^{24}\ \not{\text{kg}})}{\left(3.20\times10^{7}\ \text{m}\right)^2} \\ &= 3.89\times10^{-1}\ \text{N/kg} \end{aligned}$$

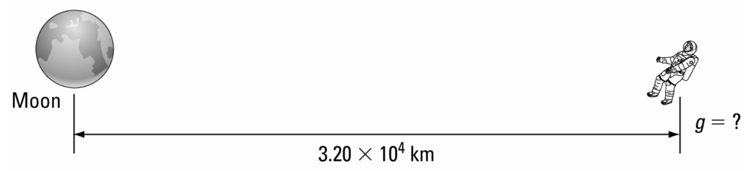
Paraphrase

The magnitude of the gravitational field strength at the location of the astronaut is 3.89×10^{-1} N/kg.

(b) ***Given***

m_a = 80.0 kg r = 3.20×10^4 km or 3.20×10^7 m

m_{Moon} = 7.35×10^{22} kg

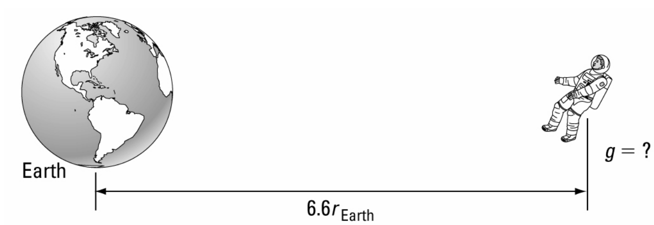


Required
magnitude of gravitational field strength at the location of astronaut (g)
Analysis and Solution
Use the equation $g = \frac{GM_{\text{source}}}{r^2}$ to calculate the magnitude of the gravitational field strength.

$$\begin{aligned} g &= \frac{Gm_{\text{Moon}}}{r^2} \\ &= \frac{\left(6.67\times10^{-11}\ \frac{\text{N•m}^2}{\text{kg}^{\not 2}}\right)(7.35\times10^{22}\ \not{\text{kg}})}{\left(3.20\times10^{7}\ \text{m}\right)^2} \\ &= 4.79\times10^{-3}\ \text{N/kg} \end{aligned}$$

Paraphrase
The magnitude of the gravitational field strength at the location of the astronaut is 4.79×10^{-3} N/kg.

3. *Given*
$m_{\text{a}} = 70$ kg
$m_{\text{Earth}} = 5.97 \times 10^{24}$ kg
$6.6r_{\text{Earth}}$
$r_{\text{Earth}} = 6.38 \times 10^6$ m



Required
gravitational force on astronaut ($\vec{F}_{\text{g}}$)
Analysis and Solution
Calculate F_{g} exerted by Earth on the astronaut using Newton's law of gravitation.

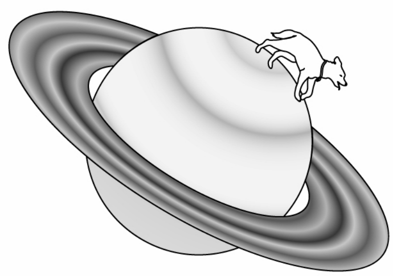
$$\begin{aligned} F_{\text{g}} &= \frac{Gm_{\text{a}}m_{\text{Earth}}}{r^2} \\ &= \frac{\left(6.67\times10^{-11}\ \frac{\text{N•m}^2}{\not{\text{kg}^2}}\right)(70\ \not{\text{kg}})(5.97\times10^{24}\ \not{\text{kg}})}{\left[6.6(6.38\times10^{6}\ \text{m})\right]^2} \\ &= 16\ \text{N} \\ \vec{F}_{\text{g}} &= 16\ \text{N [toward Earth's centre]} \end{aligned}$$

Paraphrase
The gravitational force exerted by Earth on the astronaut is 16 N [toward Earth's centre].

Student Book page 220

Example 4.6 Practice Problems

1. ***Given***
m_d = 22.0 kg
$m_{Saturn} = 5.68 \times 10^{26}$ kg
$r_{Saturn} = 6.03 \times 10^7$ m



Required
weight of dog on Saturn ($\vec{F}_g$)

Analysis and Solution
Use the equation $g = \frac{GM_{source}}{r^2}$ to calculate the magnitude of the gravitational field strength on Saturn.

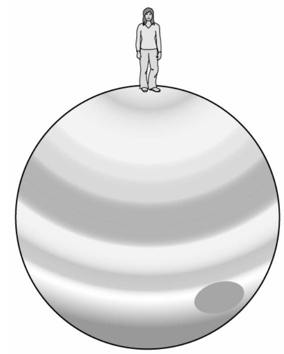
$$g_{Saturn} = \frac{Gm_{Saturn}}{(r_{Saturn})^2}$$
$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not 2}}\right)(5.68 \times 10^{26}\ \not{\text{kg}})}{\left(6.03 \times 10^7\ \text{m}\right)^2}$$
$$= 10.42\ \text{N/kg}$$

The weight of the dog is directed toward the centre of Saturn. So use the scalar form of the equation $\vec{F}_g = m\vec{g}$.

$$F_g = mg$$
$$= \left(22.0\ \not{\text{kg}}\right)\left(10.42\ \frac{\text{N}}{\not{\text{kg}}}\right)$$
$$= 229\ \text{N}$$
$$\vec{F}_g = 229\ \text{N [toward Saturn's centre]}$$

Paraphrase
On Saturn, the dog will have a weight of 229 N [toward Saturn's centre].

2. (a) and (b)
Given
$m_{Earth} = 5.97 \times 10^{24}$ kg
$m_{Jupiter} = 1.90 \times 10^{27}$ kg
$r_{Earth} = 6.38 \times 10^6$ m
$r_{Jupiter} = 7.15 \times 10^7$ m



Required
ratio of g_{Jupiter} to g_{Earth}
Analysis and Solution
Use the equation $g = \frac{GM_{\text{source}}}{r^2}$ to calculate the magnitude of the gravitational field strength on Jupiter and on Earth.
Jupiter

$$\begin{aligned} g_{\text{Jupiter}} &= \frac{Gm_{\text{Jupiter}}}{(r_{\text{Jupiter}})^2} \\ &= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not 2}}\right)(1.90 \times 10^{27}\ \cancel{\text{kg}})}{\left(7.15 \times 10^7\ \text{m}\right)^2} \\ &= 24.79\ \text{N/kg} \end{aligned}$$

Earth

$$\begin{aligned} g_{\text{Earth}} &= \frac{Gm_{\text{Earth}}}{(r_{\text{Earth}})^2} \\ &= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not 2}}\right)(5.97 \times 10^{24}\ \cancel{\text{kg}})}{\left(6.38 \times 10^6\ \text{m}\right)^2} \\ &= 9.783\ \text{N/kg} \end{aligned}$$

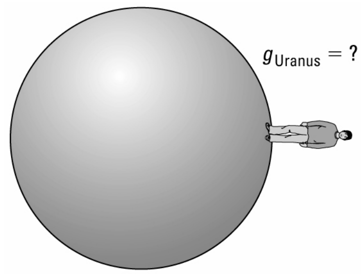
Calculate the ratio of g_{Jupiter} to g_{Earth}.

$$\begin{aligned} \frac{g_{\text{Jupiter}}}{g_{\text{Earth}}} &= \frac{24.79\ \cancel{\frac{\text{N}}{\text{kg}}}}{9.783\ \cancel{\frac{\text{N}}{\text{kg}}}} \\ &= 2.53 \end{aligned}$$

Paraphrase
(a) Even though the separation distance between me and Jupiter's centre is about 11 times greater than that between me and Earth's centre, Jupiter is about 318 times more massive than Earth. So my skeleton would not be able to support my weight on Jupiter.
(b) My bones would have to be 2.53 times stronger on Jupiter.

3. (a) ***Given***

$m_{\text{Uranus}} = 8.68 \times 10^{25}$ kg $r_{\text{Uranus}} = 2.56 \times 10^{7}$ m



Required

magnitude of gravitational field strength at the surface of Uranus (g_{Uranus})

Analysis and Solution

Use the equation $g = \dfrac{GM_{\text{source}}}{r^2}$ to calculate the magnitude of the gravitational field strength on Uranus.

$$g_{\text{Uranus}} = \frac{Gm_{\text{Uranus}}}{(r_{\text{Uranus}})^2}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N}\cdot\text{m}^2}{\text{kg}^{\not 2}}\right)(8.68 \times 10^{25}\ \not{\text{kg}})}{\left(2.56 \times 10^{7}\ \text{m}\right)^2}$$

$= 8.83$ N/kg

Paraphrase

The magnitude of the gravitational field strength at the surface of Uranus is 8.83 N/kg.

(b) ***Analysis and Solution***

Calculate the ratio of g_{Uranus} to g_{Earth}.

$$\frac{g_{\text{Uranus}}}{g_{\text{Earth}}} = \frac{8.834\ \frac{\not{\text{N}}}{\not{\text{kg}}}}{9.783\ \frac{\not{\text{N}}}{\not{\text{kg}}}}$$

$= 0.903$

Paraphrase

My weight on Uranus would be 0.903 that on Earth.

Student Book page 221

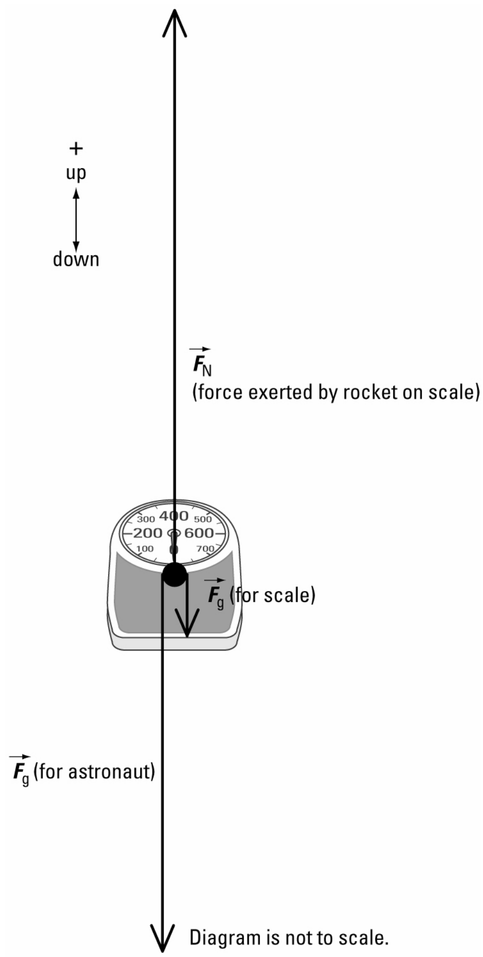
Concept Check

Leo may not weigh 638 N at other places due to differences in gravitational field strength at different locations on Earth's surface. Latitude, altitude, variations in distance from Earth's centre, and the density of the mantle can affect the gravitational field strength, which affects Leo's weight. It would be more accurate for Leo to state his mass (either gravitational or inertial).

Student Book page 225

Example 4.7 Practice Problems

1.



2. ***Given***

$m = 100.0$ kg

$\vec{a} = 19.6 \text{ m/s}^2$ [down]

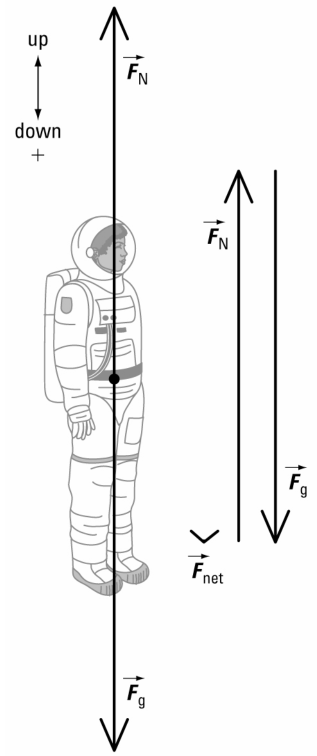
$\vec{g} = 9.81 \text{ m/s}^2$ [down]

Required

apparent weight and true weight ($\vec{w}$ and $\vec{F}_g$)

Analysis and Solution

Draw a free-body diagram for the astronaut.



Use the equation $\vec{F}_g = m\,\vec{g}$ to find the astronaut's true weight.

$$\begin{aligned}
\vec{F}_g &= m\,\vec{g} \\
F_g &= mg \\
&= (100.0 \text{ kg})(9.81 \text{ m/s}^2) \\
&= 9.81 \times 10^2 \text{ N} \\
\vec{F}_g &= 9.81 \times 10^2 \text{ N [down]}
\end{aligned}$$

The astronaut is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the astronaut.

$$\begin{aligned}
\vec{F}_{net} &= \vec{F}_g + \vec{F}_N \\
F_{net} &= F_g + F_N
\end{aligned}$$

Apply Newton's second law.

$$\begin{aligned}
ma &= F_g + F_N \\
F_N &= ma - F_g \\
&= (100.0 \text{ kg})(19.6 \text{ m/s}^2) - 9.81 \times 10^2 \text{ N} \\
&= 9.79 \times 10^2 \text{ N} \\
\vec{F}_N &= 9.79 \times 10^2 \text{ N [up]}
\end{aligned}$$

Use the equation $\vec{w} = -\vec{F}_N$ to find the astronaut's apparent weight.

$$\begin{aligned}
\vec{w} &= -\vec{F}_N \\
&= 9.79 \times 10^2 \text{ N [down]}
\end{aligned}$$

Paraphrase
The astronaut has an apparent weight of 9.79×10^2 N [down] and a true weight of 9.81×10^2 N [down].

Example 4.8 Practice Problems

1. (a) ***Given***

$m = 80.0$ kg

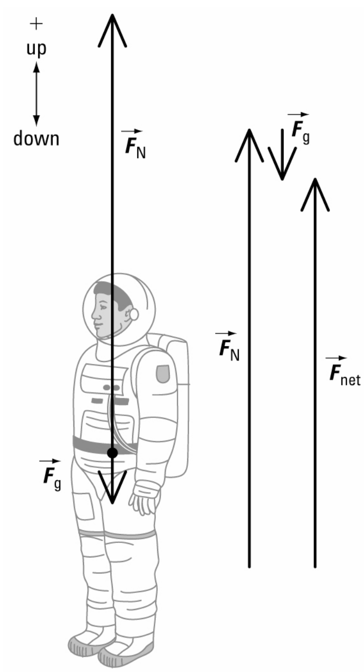
$\vec{a} = 12.8 \text{ m/s}^2$ [up] $\quad\quad \vec{g}_{\text{Moon}} = 1.62$ N/kg [down]

Required

true weight and apparent weight during liftoff ($\vec{F}_g$ and $\vec{w}$)

Analysis and Solution

Draw a free-body diagram for the astronaut.



Use the equation $\vec{F}_g = m\,\vec{g}$ to find the astronaut's true weight.

$$\vec{F}_g = m\,\vec{g}_{\text{Moon}}$$

$$\begin{aligned} F_g &= mg_{\text{Moon}} \\ &= (80.0 \text{ kg})\left(-1.62 \frac{\text{N}}{\text{kg}}\right) \\ &= -1.30 \times 10^2 \text{ N} \end{aligned}$$

$$\vec{F}_g = 1.30 \times 10^2 \text{ N [down]}$$

The astronaut is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$

$F_{net} = F_g + F_N$

Apply Newton's second law.

$ma = F_g + F_N$

$F_N = ma - F_g$

$= (80.0 \text{ kg})(12.8 \text{ m/s}^2) - (-1.30 \times 10^2 \text{ N})$

$= (80.0 \text{ kg})(12.8 \text{ m/s}^2) + 1.30 \times 10^2 \text{ N}$

$= 1.15 \times 10^3 \text{ N}$

$\vec{F}_N = 1.15 \times 10^3 \text{ N [up]}$

Use the equation $\vec{w} = -\vec{F}_N$ to find the astronaut's apparent weight.

$\vec{w} = -\vec{F}_N$

$= 1.15 \times 10^3 \text{ N [down]}$

Paraphrase

During liftoff, the astronaut has a true weight of 1.30×10^2 N [down] and an apparent weight of 1.15×10^3 N [down].

(b) ***Given***

$m = 80.0$ kg

$\vec{a} = 12.8 \text{ m/s}^2$ [up] $\qquad \vec{g} = 0$ N/kg

Required

true weight and apparent weight in deep space ($\vec{F}_g$ and $\vec{w}$)

Analysis and Solution

In deep space, the mass of the astronaut is still 80.0 kg, but $\vec{g} = 0$ N/kg.

So, $\vec{F}_g = m\vec{g}$

$\vec{F}_g = 0 \text{ N}$

The astronaut is not accelerating left or right.

So in the horizontal direction, $\vec{F}_{net} = 0$ N.

For the vertical direction, write an equation to find the net force on the astronaut.

$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$

$F_{net} = F_g + F_N$

Apply Newton's second law.

$ma = 0 + F_N$

$F_N = ma$

$= (80.0 \text{ kg})(12.8 \text{ m/s}^2)$

$= 1.02 \times 10^3 \text{ N}$

$\vec{F}_N = 1.02 \times 10^3 \text{ N [up]}$

Use the equation $\vec{w} = -\vec{F}_N$ to find the astronaut's apparent weight.

$\vec{w} = -\vec{F}_N$

$= 1.02 \times 10^3 \text{ N [down]}$

Paraphrase

In deep space, the astronaut has a true weight of 0 N and an apparent weight of 1.02×10^3 N [down].

2. (a) ***Given***

m_a = 60.0 kg

$\vec{a}$ = –11.1 m/s^2 [down]

m_{Mars} = 6.42 × 10^{23} kg $\quad$ r_{Mars} = 3.40 × 10^6 m

Required

true weight and apparent weight ($\vec{F}_g$ and $\vec{w}$)

Analysis and Solution

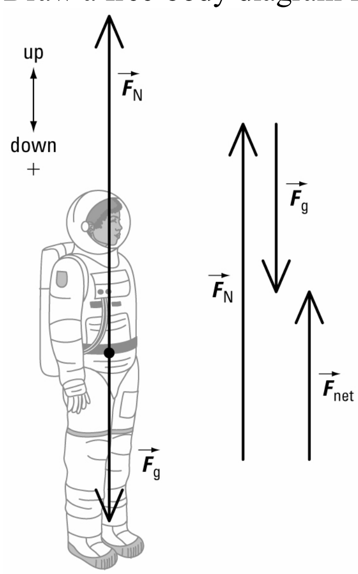
Use the equation $g = \frac{GM_{source}}{r^2}$ to calculate the magnitude of the gravitational field strength on Mars.

$$g_{Mars} = \frac{Gm_{Mars}}{(r_{Mars})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N•m}^2}{\text{kg}^{\not 2}}\right)(6.42\times10^{23}\ \not{\text{kg}})}{\left(3.40\times10^6\ \text{m}\right)^2}$$

$$= 3.704 \text{ N/kg}$$

Draw a free-body diagram for the astronaut.



Use the equation $\vec{F}_g = m\vec{g}$ to find the astronaut's true weight.

$\vec{F}_g = m_a\vec{g}_{Mars}$

$F_g = m_a g_{Mars}$

$= (60.0\ \not{\text{kg}})\left(3.704\ \frac{\text{N}}{\not{\text{kg}}}\right)$

$= 2.22 \times 10^2$ N

$\vec{F}_g = 2.22 \times 10^2$ N [down]

The astronaut is not accelerating left or right.

So in the horizontal direction, $\vec{F}_{net}$ = 0 N.

For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$

$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$$m_a a = F_g + F_N$$

$$F_N = m_a a - F_g$$

$$= (60.0 \text{ kg})(-11.1 \text{ m/s}^2) - 2.22 \times 10^2 \text{ N}$$

$$= -8.88 \times 10^2 \text{ N}$$

$$\vec{F}_N = 8.88 \times 10^2 \text{ N [up]}$$

Use the equation $\vec{w} = -\vec{F}_N$ to find the astronaut's apparent weight.

$$\vec{w} = -\vec{F}_N$$

$$= 8.88 \times 10^2 \text{ N [down]}$$

Paraphrase

The astronaut has a true weight of 2.22×10^2 N [down] and an apparent weight of 8.88×10^2 N [down].

(b) ***Given***

$m_a = 60.0$ kg

$\vec{a} = 7.38$ m/s^2 [up]

$m_{Mars} = 6.42 \times 10^{23}$ kg $\quad r_{Mars} = 3.40 \times 10^6$ m

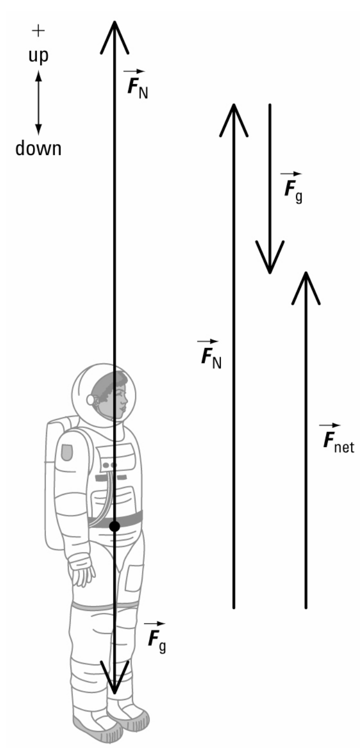
$g_{Mars} = 3.704$ N/kg from part (a)

Required

true weight and apparent weight ($\vec{F}_g$ and $\vec{w}$)

Analysis and Solution

Draw a free-body diagram for the astronaut.



Use the equation $\vec{F}_g = m\vec{g}$ to find the astronaut's true weight.

$$\vec{F}_g = m_a \vec{g}_{Mars}$$
$$F_g = m_a g_{Mars}$$
$$= (60.0 \text{ kg})\left(-3.704 \frac{\text{N}}{\text{kg}}\right)$$
$$= -2.22 \times 10^2 \text{ N}$$
$$\vec{F}_g = 2.22 \times 10^2 \text{ N [down]}$$

The astronaut is not accelerating left or right.

So in the horizontal direction, $\vec{F}_{net} = 0$ N.

For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$
$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$$m_a a = F_g + F_N$$
$$F_N = m_a a - F_g$$
$$= (60.0 \text{ kg})(7.38 \text{ m/s}^2) - (-2.22 \times 10^2 \text{ N})$$
$$= (60.0 \text{ kg})(7.38 \text{ m/s}^2) + 2.22 \times 10^2 \text{ N}$$
$$= 6.65 \times 10^2 \text{ N}$$
$$\vec{F}_N = 6.65 \times 10^2 \text{ N [up]}$$

Use the equation $\vec{w} = -\vec{F}_N$ to find the astronaut's apparent weight.

$$\vec{w} = -\vec{F}_N$$
$$= 6.65 \times 10^2 \text{ N [down]}$$

Paraphrase

The astronaut has a true weight of 2.22×10^2 N [down] and an apparent weight of 6.65×10^2 N [down].

Student Book page 229

4.3 Check and Reflect

Knowledge

1. (a) True weight is the gravitational force exerted by a celestial body, such as Earth, on an object. The equation to determine true weight is $\vec{F}_g = m\vec{g}$. True weight depends on the mass of the object and the magnitude of the gravitational field strength at the location of the object, which may or may not be zero.

Apparent weight is equal in magnitude but opposite in direction to the normal force acting on an object, $\vec{w} = -\vec{F}_N$. The apparent weight is determined by first calculating the net force on the object. Once you know the normal force, the apparent weight is the negative of $\vec{F}_N$.

(b) In deep space, an object does not experience any measurable gravitational forces. So the object has a true weight of zero, even though the object has mass. If the object has an acceleration of $\vec{a}$ in deep space, its apparent weight will be $\vec{w} = -m\vec{a}$, which is not zero.

2. When a person is orbiting Earth in a spacecraft, both the person and the spacecraft are falling toward Earth with an acceleration equal in magnitude to the gravitational field strength at that location.

The net force on the person is
$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$
$$F_{net} = F_g + F_N$$
$$ma = mg + F_N$$
So the normal force is
$$F_N = m(a - g)$$
Since $a = g$, $F_N = 0$, and the apparent weight $\vec{w}$ is also zero.

So even though the person has an apparent weight of zero, the person still experiences a gravitational force.

3. Two factors that affect the magnitude of the gravitational field strength at Earth's surface are altitude and latitude, which are both related to the distance from Earth's centre. The magnitude of the gravitational field strength decreases as a person climbs a mountain, but increases as a person treks toward the geographic poles.

Applications

4. In deep space, far away from any celestial body, the gravitational field strength is not measurable and its magnitude approaches zero. Only at an infinite distance from all celestial bodies would this situation exist.

Since the magnitude of the gravitational field strength is given by $g = \frac{GM_{source}}{r^2}$, when r approaches infinity, $\frac{GM_{source}}{r^2}$ becomes very small. So g approaches zero.

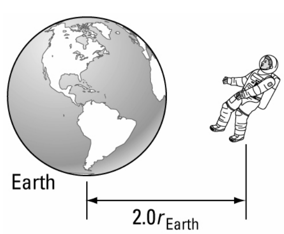
5. ***Given***

$m_a = 70$ kg

$m_{Earth} = 5.97 \times 10^{24}$ kg

$2.0r_{Earth}$

$r_{Earth} = 6.38 \times 10^6$ m



Required

gravitational field strength at the location of astronaut ($\vec{g}$)

Analysis and Solution

Use the equation $g = \frac{GM_{source}}{r^2}$ to calculate the magnitude of the gravitational field strength.

$$g = \frac{Gm_{Earth}}{r^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not{2}}}\right)(5.97\times10^{24}\ \not{\text{kg}})}{\left[2.0\left(6.38\times10^{6}\ \text{m}\right)\right]^2}$$

$= 2.4$ N/kg

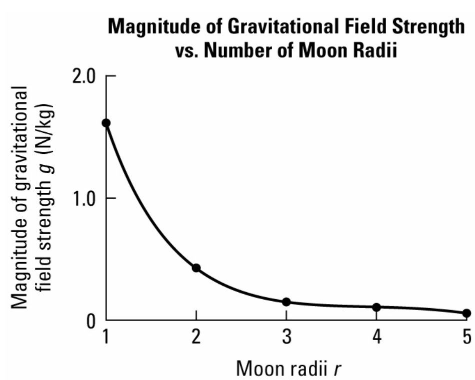
$\vec{g}$ = 2.4 N/kg [toward Earth's centre]

Paraphrase

The gravitational field strength at the location of the astronaut is 2.4 N/kg [toward Earth's centre].

6. Graphing calculator keystrokes for drawing the curve

- Clear RAM. Press [2nd] [MEM].
  Press [7]. Press [1]. Press [2].
- Press [Mode] and select [Normal].
- Press [Window] and enter $X_{min} = 1.0$, $X_{max} = 5.0$, $Y_{min} = 0$, and $Y_{max} = 2.0$.
- Press [Y=] and enter $y = 1.6/x^2$ for Y1. The variable y corresponds to g and x to r in terms of moon radii.
- Press [Graph].



Graphing calculator keystrokes for reading the coordinates of the curve

- Press [2nd] [Calc] and select [5] [Intersect].
- Use the [◁] and [▷] keys to toggle the curve and read values of y for the values of x specified in this question.
- For values to the nearest decimal place, press [Zoom] [4] and toggle to the required value of x. Read off the values of y.

(a) The graph of g vs. r_{Moon} is the same shape as Figure 4.10 on page 201. As the distance from the Moon's surface increases, the magnitude of the gravitational field strength decreases.

(b) (i) The Moon's surface corresponds to r_{Moon}. The value of g at r_{Moon} is 1.6 N/kg.

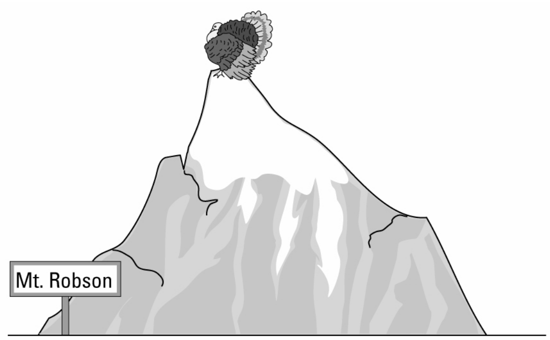
(ii) $\frac{1}{2}r_{\text{Moon}}$ above the Moon's surface corresponds to $1.5r_{\text{Moon}}$. The value of g at $1.5r_{\text{Moon}}$ is 0.72 N/kg.

(iii) r_{Moon} above the Moon's surface corresponds to $2.0r_{Moon}$. The value of g at $2.0r_{Moon}$ is 0.40 N/kg.

(c) As the distance from the Moon's centre approaches $4r_{Moon}$, the magnitude of the gravitational field strength approaches zero, or 0.10 N/kg. By resetting X_{max} on the graphing calculator to $10r_{Moon}$, the magnitude of the gravitational field strength becomes 0.016 N/kg. When $r = 100r_{Moon}$, the magnitude of the gravitational field strength is 1.6×10^{-4} N/kg, which is 100 times smaller.

7. ***Given***

$m = 7.5$ kg $\qquad \vec{F}_g = 73.6$ N [down]



Required

magnitude of gravitational field strength at the location of turkey (g)

Analysis and Solution

The gravitational field strength is in the same direction as the gravitational force. So use the scalar form of the equation $\vec{F}_g = m\vec{g}$.

$$\begin{aligned} F_g &= mg \\ g &= \frac{F_g}{m} \\ &= \frac{73.6 \text{ N}}{7.5 \text{ kg}} \\ &= 9.8 \text{ N/kg} \end{aligned}$$

Paraphrase

The magnitude of gravitational field strength at the location of turkey is 9.8 N/kg.

8. ***Given***

$\vec{w} = 1.35 \times 10^3$ N [down]

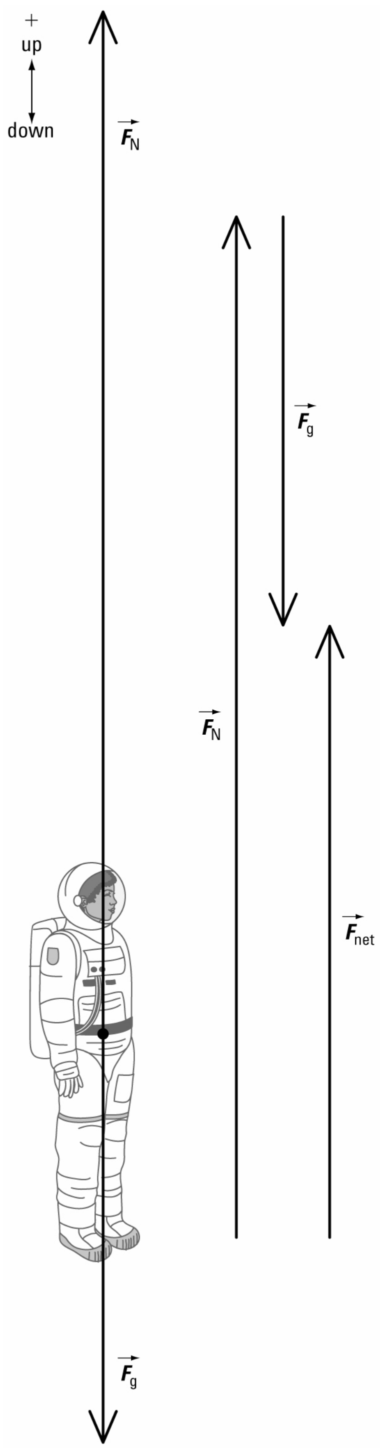
$\vec{a} = 14.7$ m/s^2 [up] $\qquad \vec{g} = 9.81$ m/s^2 [down]

Required

true weight ($\vec{F}_g$)

Analysis and Solution

Draw a free-body diagram for the astronaut.



Since $\vec{w} = -\vec{F}_N$, $F_N = 1.35 \times 10^3$ N.
The astronaut is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$

$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$$\begin{aligned} ma &= mg + F_N \\ m(a - g) &= F_N \\ m &= \frac{F_N}{a - g} \\ &= \frac{1.35 \times 10^3 \text{ N}}{14.7 \text{ m/s}^2 - (-9.81 \text{ m/s}^2)} \\ &= \frac{1.35 \times 10^3 \text{ kg}\bullet\frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}{24.51 \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}} \\ &= 55.08 \text{ kg} \end{aligned}$$

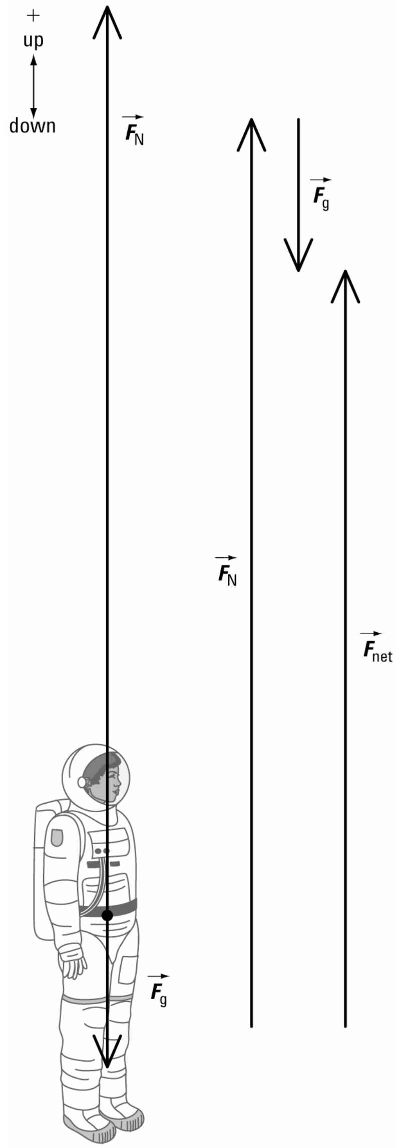
Substitute the mass of the astronaut into the equation $\vec{F}_g = m\vec{g}$ to find the astronaut's true weight.

$$\begin{aligned} \vec{F}_g &= m\vec{g} \\ F_g &= mg \\ &= (55.08 \text{ kg})(-9.81 \text{ m/s}^2) \\ &= -540 \text{ N} \\ \vec{F}_g &= 540 \text{ N [down]} \end{aligned}$$

Paraphrase

The astronaut has a true weight of 540 N [down].

9. (a)



(b) ***Given***

m = 50 kg

$\vec{a}$ = 5.0g [up] $\qquad\qquad$ $\vec{g}$ = 9.81 N/kg [down]

Required

true weight and apparent weight ($\vec{F}_g$ and $\vec{w}$)

Analysis and Solution

Use the equation $\vec{F}_g = m\vec{g}$ to find the astronaut's true weight.

$$\begin{aligned}\vec{F}_g &= m\vec{g}\\ F_g &= mg\\ &= (50\ \text{kg})\left(-9.81\ \frac{\text{N}}{\text{kg}}\right)\\ &= -4.9 \times 10^2\ \text{N}\end{aligned}$$

$\vec{F}_g = 4.9 \times 10^2$ N [down]

The astronaut is not accelerating left or right.

So in the horizontal direction, $\vec{F}_{net} = 0$ N.

For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$
$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$$ma = F_g + F_N$$
$$F_N = ma - F_g$$
$$= (50\ \cancel{kg})(5.0)\left(9.81\ \frac{N}{\cancel{kg}}\right) - (-4.9 \times 10^2\ N)$$
$$= (50)(5.0)(9.81\ N) + 4.9 \times 10^2\ N$$
$$= 2.9 \times 10^3\ N$$
$$\vec{F}_N = 2.9 \times 10^3\ N\ [up]$$

Use the equation $\vec{w} = -\vec{F}_N$ to find the astronaut's apparent weight.

$$\vec{w} = -\vec{F}_N$$
$$= 2.9 \times 10^3\ N\ [down]$$

Paraphrase

The astronaut has a true weight of 4.9×10^2 N [down] and an apparent weight of 2.9×10^3 N [down].

10. Figure 4.38

Given

$\vec{F}_g = 600$ N [down] $\quad \vec{F}_N = 750$ N [up]

$\vec{g} = 9.81$ m/s^2 [down]

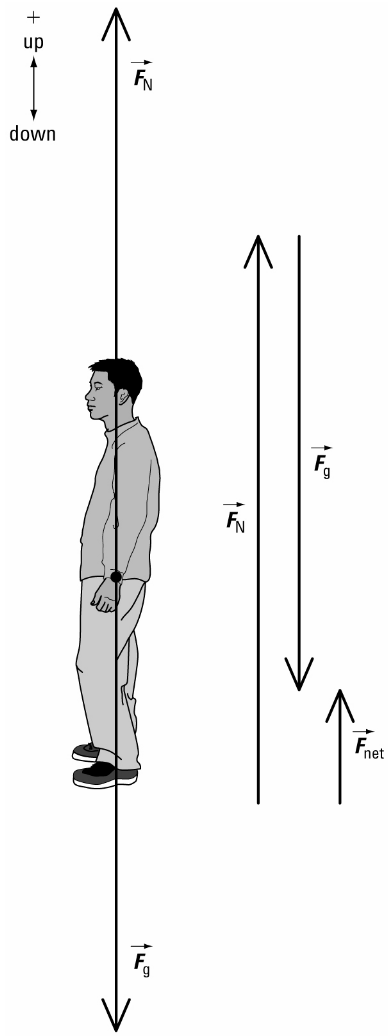
Required

acceleration of elevator ($\vec{a}$)

Analysis and Solution

Since the student is standing on the elevator floor, both he and the elevator will have the same vertical acceleration.

Draw a free-body diagram for the student.



Use the equation $\vec{F}_g = m\vec{g}$ to find the student's mass.

$$\begin{aligned}
\vec{F}_g &= m\vec{g} \\
F_g &= mg \\
m &= \frac{F_g}{g} \\
&= \frac{-600\ \text{N}}{-9.81\ \text{m/s}^2} \\
&= \frac{-600\ \text{kg}\bullet \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}{-9.81\ \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}} \\
&= 61.16\ \text{kg}
\end{aligned}$$

The student is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the student.

$$\vec{F}_{\text{net}} = \vec{F}_{\text{g}} + \vec{F}_{\text{N}}$$

$$F_{\text{net}} = F_{\text{g}} + F_{\text{N}}$$

Apply Newton's second law.

$$\begin{aligned} ma &= F_{\text{g}} + F_{\text{N}} \\ &= -600\text{ N} + 750\text{ N} \\ (61.16\text{ kg})a &= 150\text{ N} \\ a &= \frac{150\text{ N}}{61.16\text{ kg}} \\ &= \frac{150\ \cancel{\text{kg}} \bullet \frac{\text{m}}{\text{s}^2}}{61.16\ \cancel{\text{kg}}} \\ &= 2.45\text{ m/s}^2 \\ \vec{a} &= 2.45\text{ m/s}^2\text{ [up]} \end{aligned}$$

Paraphrase

The elevator has an acceleration of 2.45 m/s^2 [up].

Figure 4.40

Given

$\vec{F}_{\text{g}}$ = 600 N [down]

$\vec{F}_{\text{N}}$ = 525 N [up]

$\vec{g}$ = 9.81 m/s^2 [down]

m = 61.16 kg

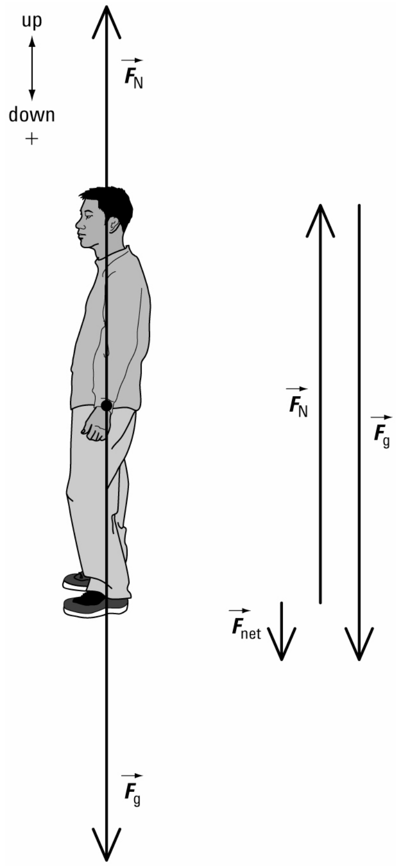
Required

acceleration of elevator ($\vec{a}$)

Analysis and Solution

Since the student is standing on the elevator floor, both he and the elevator will have the same vertical acceleration.

Draw a free-body diagram for the student.



The student is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the student.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$

$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$$\begin{aligned} ma &= F_g + F_N \\ &= 600 \text{ N} + (-525 \text{ N}) \\ &= 600 \text{ N} - 525 \text{ N} \end{aligned}$$

$$(61.16 \text{ kg})a = 75 \text{ N}$$

$$a = \frac{75 \text{ N}}{61.16 \text{ kg}}$$

$$= \frac{75 \cancel{\text{kg}} \cdot \frac{\text{m}}{\text{s}^2}}{61.16 \cancel{\text{kg}}}$$

$$= 1.23 \text{ m/s}^2$$

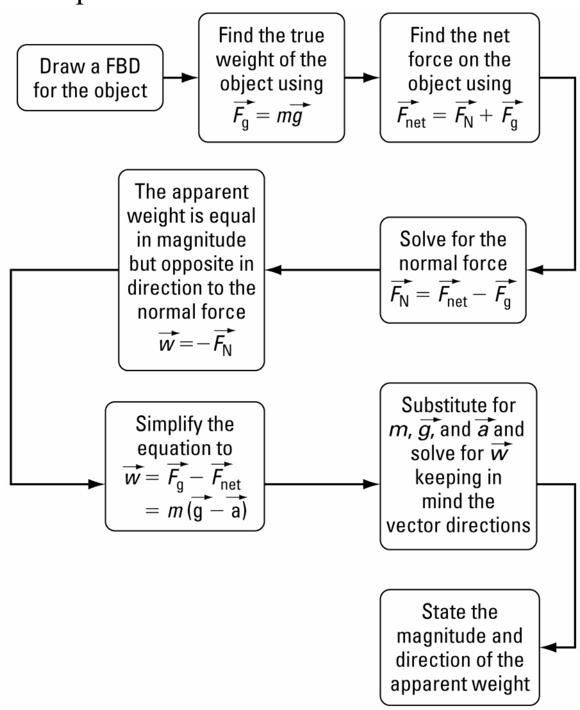
$$\vec{a} = 1.23 \text{ m/s}^2 \text{ [down]}$$

Paraphrase

The elevator has an acceleration of 1.23 m/s^2 [down].

Extensions

11. For example:



12. Geophysicists use gravimeters to measure the magnitude of the gravitational field strength at different locations on Earth's surface. They can predict what the magnitude of the gravitational field strength should be at a given elevation. If g is greater than expected, there may be a dense mineral, such as gold or silver, beneath the surface, but if g is less than expected, there may be a material of lower density, such as natural gas or oil.

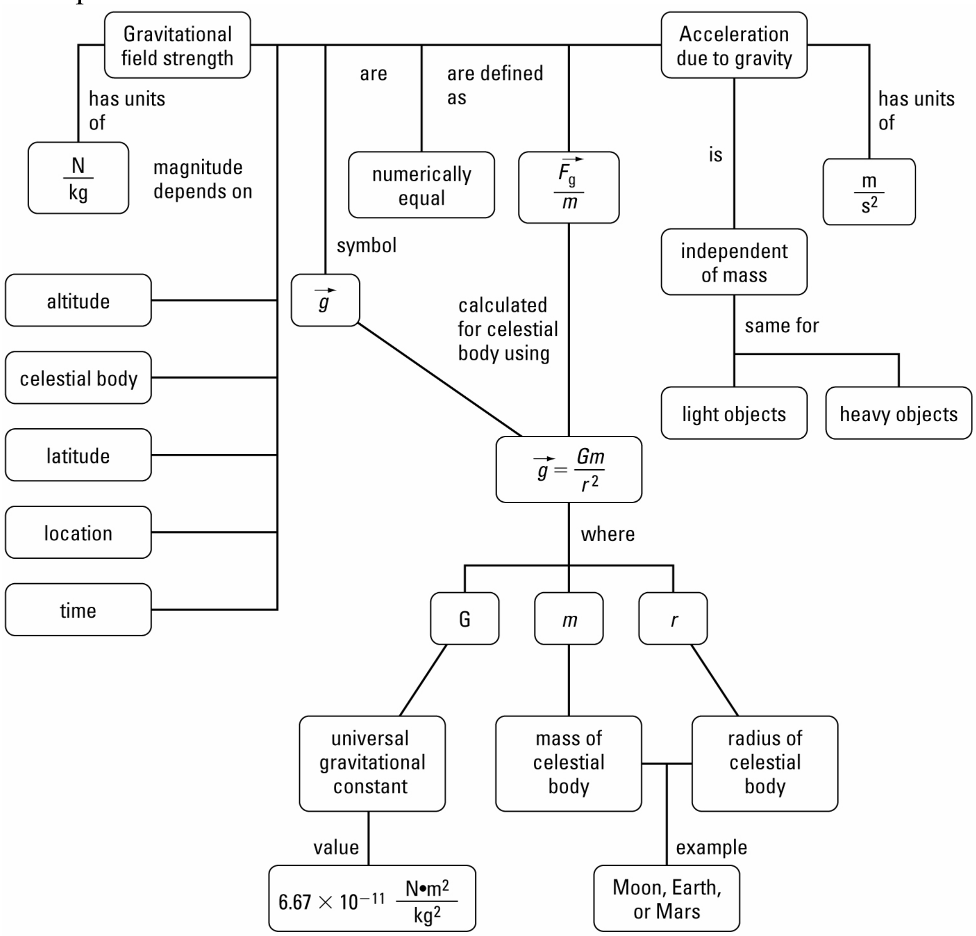
13. Although the combined mass of the person and spacesuit does not change, the magnitude of the gravitational field strength on the Moon is about $\frac{1}{6}$ that on Earth. In order to walk, the person must exert a backward force with each step, which results in a reaction force that accelerates the person forward. Since on the Moon, the magnitude of the combined weight of the person and spacesuit is $\frac{1}{6}$ that on Earth, the person's muscles don't have to work as hard to walk. So the person will find it easier to walk on the Moon than on Earth.

In terms of the vertical forces, on the Moon, the gravitational force is about $\frac{1}{6}$ its magnitude on Earth. The Moon also exerts a normal force directed up on the person. Since the normal force is equal in magnitude but opposite in direction to the gravitational force, there is no vertical acceleration.

If the person jumps up, both feet must push down with a force of greater magnitude than the combined weight. The reaction force exerted by the ground must overcome the combined weight and accelerate the person up. Since g on the Moon is less than that on Earth, the person can jump higher on the Moon than on Earth.

Have students draw free-body diagrams, on Earth and on the Moon, when a person is standing still, jumping up, and walking.

14. For example:



Example Problem

What is the acceleration due to gravity on Neptune? Explain how the free fall acceleration of an object on Neptune would compare with that on Earth.

Scoring Hints

Check for students' understanding of the concepts in the concept map, and their ability to correctly use the data in Table 4.1, the numerical values of the variables, and the value of the universal gravitational constant. See if students understand that gravitational field strength and acceleration due to gravity are numerically equal.

Student Book page 231

Chapter 4 Review

Knowledge

1. In Newton's law of universal gravitation, the term "universal" means that this law applies not just on Earth, but throughout the universe.

2. ***Given***

$m = 5.0$ kg $\quad\quad g_{\text{planet}} = 2.0g_{\text{Earth}}$

$F_g = 48$ N

Required

reading on spring scale and on equal arm balance on other planet

Analysis and Solution

Use the scalar form of the equation $\vec{F}_g = m\vec{g}$ to find the magnitude of the gravitational field strength on Earth.

$$\begin{aligned} F_g &= mg \\ g &= \frac{F_g}{m} \\ &= \frac{48\text{ N}}{5.0\text{ kg}} \\ &= 9.6\text{ N/kg} \end{aligned}$$

Calculate the magnitude of the gravitational field strength on the other planet.

$$\begin{aligned} g_{\text{planet}} &= 2.0g_{\text{Earth}} \\ &= 2.0 \times 9.6\text{ N/kg} \\ &= 19.2\text{ N/kg} \end{aligned}$$

Use the scalar form of the equation $\vec{F}_g = m\vec{g}$ to find the reading on the spring scale on the other planet.

$$\begin{aligned} F_g &= mg_{\text{planet}} \\ &= (5.0\ \cancel{\text{kg}})\left(19.2\ \frac{\text{N}}{\cancel{\text{kg}}}\right) \\ &= 96\text{ N} \end{aligned}$$

The reading on the equal arm balance will still be 5.0 kg on the other planet.

Paraphrase

The reading on the spring scale will be 96 N and on the equal arm balance 5.0 kg.

3. Since the gravitational field strength is given by $g = \frac{GM_{\text{source}}}{r^2}$ and r is assumed to be constant, g is directly proportional to the mass of the celestial body, $g \propto M_{\text{source}}$.

4. ***Given***

$1.6r_{\text{Earth}}$

$\vec{g} = 9.81$ N/kg [toward Earth's centre] at Earth's surface

Required

gravitational field strength ($\vec{g}$)

Analysis and Solution

From the equation $g = \frac{GM_{\text{source}}}{r^2}$, $g \propto \frac{1}{r^2}$.

$$\begin{aligned} g &\propto \frac{1}{(1.6r)^2} \\ &\propto \left(\frac{1}{1.6^2}\right)\left(\frac{1}{r^2}\right) \end{aligned}$$

Calculate g.

$$\left(\frac{1}{1.6^2}\right)g = \frac{1}{1.6^2} \times (9.81 \text{ N/kg})$$
$$= 3.8 \text{ N/kg}$$
$$\vec{g} = 3.8 \text{ N/kg [toward Earth's centre]}$$

Paraphrase

The gravitational field strength at $1.6r_{\text{Earth}}$ from Earth's centre is 3.8 N/kg [toward Earth's centre].

Applications

5. ***Given***

$m_{\text{A}} = 1.0$ kg $m_{\text{B}} = 2.0$ kg
$\vec{v}_{\text{i}} = 0$ m/s $\Delta t = 2.26$ s
$m_{\text{Jupiter}} = 1.90 \times 10^{27}$ kg $r_{\text{Jupiter}} = 7.15 \times 10^{7}$ m
$d = 25$ m

Required

time taken to fall 25 m on Jupiter (Δt)

Analysis and Solution

Use the equation $g = \frac{GM_{\text{source}}}{r^2}$ to calculate the magnitude of the gravitational acceleration on Jupiter.

$$g_{\text{Jupiter}} = \frac{Gm_{\text{Jupiter}}}{(r_{\text{Jupiter}})^2}$$
$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not 2}}\right)(1.90\times10^{27}\ \not{\text{kg}})}{\left(7.15\times10^{7}\ \text{m}\right)^2}$$
$$= 24.8 \text{ m/s}^2$$

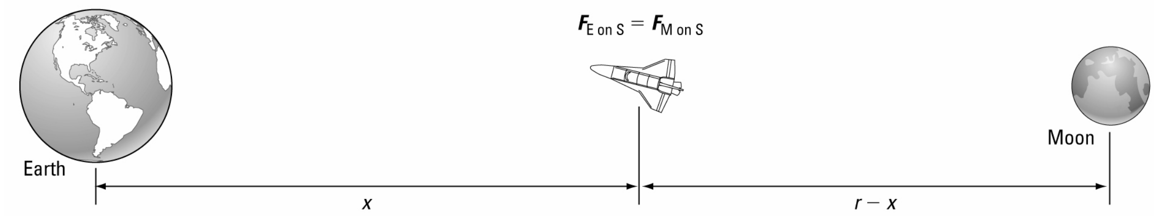
Calculate the time interval.

$$d = \left(\frac{1}{2}\right)g_{\text{Jupiter}}(\Delta t)^2$$
$$(\Delta t)^2 = \frac{2d}{g_{\text{Jupiter}}}$$
$$\Delta t = \sqrt{\frac{2d}{g_{\text{Jupiter}}}}$$
$$= \sqrt{\frac{2(25 \text{ m})}{24.8 \text{ m/s}^2}}$$
$$\Delta t = 1.4 \text{ s}$$

Paraphrase

The 2.0-kg object will take 1.4 s to fall 25 m on Jupiter.

6. Label the separation distance between Earth's centre and the Moon's centre as r. The separation distance between the spacecraft and Earth is x. So the separation distance between the spacecraft and the Moon is $r - x$.



Use the equation $g = \frac{GM_{\text{source}}}{r^2}$ to find the magnitude of the gravitational field strength at the location of the spacecraft. Express this magnitude in terms of x and $r - x$.
Use the values of m_{Earth} and m_{Moon} from Table 4.1 and set both expressions for g equal to each other.
Then solve for r.

For students who want the challenge of solving the problem numerically, here is the solution:

Given

$m_{\text{Earth}} = 5.97 \times 10^{24}$ kg $\qquad r = 3.82 \times 10^8$ m
$m_{\text{Moon}} = 7.35 \times 10^{22}$ kg

Required

separation distance between spacecraft and Earth and between spacecraft and the Moon

Analysis and Solution

See explanation above.

$$g = \frac{Gm_{\text{Earth}}}{x^2} \quad \text{and} \quad g = \frac{Gm_{\text{Moon}}}{\left(3.82\times10^8\ \text{m} - x\right)^2}$$

$$\frac{\cancel{G}m_{\text{Earth}}}{x^2} = \frac{\cancel{G}m_{\text{Moon}}}{\left(3.82\times10^8\ \text{m} - x\right)^2}$$

$$\frac{\sqrt{m_{\text{Earth}}}}{x} = \frac{\sqrt{m_{\text{Moon}}}}{3.82\times10^8\ \text{m} - x}$$

$$\begin{aligned}
\left(\sqrt{m_{\text{Moon}}}\right) x &= \left(\sqrt{m_{\text{Earth}}}\right)(3.82\times10^8\ \text{m} - x) \\
&= \left(\sqrt{m_{\text{Earth}}}\right)(3.82\times10^8\ \text{m}) - \left(\sqrt{m_{\text{Earth}}}\right) x \\
\left(\sqrt{m_{\text{Moon}}} + \sqrt{m_{\text{Earth}}}\right) x &= \left(\sqrt{m_{\text{Earth}}}\right)(3.82\times10^8\ \text{m}) \\
x &= \left(\frac{\sqrt{m_{\text{Earth}}}}{\sqrt{m_{\text{Moon}}} + \sqrt{m_{\text{Earth}}}}\right)(3.82\times10^8\ \text{m}) \\
&= \left(\frac{\sqrt{5.97\times10^{24}\ \text{kg}}}{\sqrt{7.35\times10^{22}\ \text{kg}} + \sqrt{5.97\times10^{24}\ \text{kg}}}\right)(3.82\times10^8\ \text{m}) \\
&= 3.44\times10^8\ \text{m} \\
\text{So } 3.82\times10^8\ \text{m} - x &= 3.82\times10^8\ \text{m} - 3.439\times10^8\ \text{m} \\
&= 3.82\times10^7\ \text{m}
\end{aligned}$$

Paraphrase
The spacecraft would have to be 3.44×10^8 m from Earth's centre and 3.82×10^7 m from the Moon's centre in order for the gravitational force to be balanced by both celestial bodies.

7. (a) ***Given***

m_a = 60.0 kg
$m_{Mars} = 6.42 \times 10^{23}$ kg $\qquad r_{Mars} = 3.40 \times 10^6$ m

Required

true weight on Mars ($\vec{F}_g$)

Analysis and Solution

Use the equation $g = \frac{GM_{source}}{r^2}$ to calculate the magnitude of the gravitational field strength on Mars.

$$\begin{aligned} g_{Mars} &= \frac{Gm_{Mars}}{(r_{Mars})^2} \\ &= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N•m}^2}{\text{kg}^{\not{2}}}\right)(6.42 \times 10^{23}\ \not{\text{kg}})}{\left(3.40 \times 10^6\ \text{m}\right)^2} \\ &= 3.704\ \text{N/kg} \end{aligned}$$

The weight of the astronaut is directed toward the centre of Mars. So use the scalar form of the equation $\vec{F}_g = m\vec{g}$.

$$\begin{aligned} F_g &= m_a g_{Mars} \\ &= \left(60.0\ \not{\text{kg}}\right)\left(3.704\ \frac{\text{N}}{\not{\text{kg}}}\right) \\ &= 2.22 \times 10^2\ \text{N} \\ \vec{F}_g &= 2.22 \times 10^2\ \text{N [toward centre of Mars]} \end{aligned}$$

Paraphrase

On Mars, the astronaut has a true weight of 2.22×10^2 N [toward centre of Mars].

(b) ***Given***

m_a = 60.0 kg
$m_{Saturn} = 5.68 \times 10^{26}$ kg $\qquad r_{Saturn} = 6.03 \times 10^7$ m

Required

true weight on Saturn ($\vec{F}_g$)

Analysis and Solution

Use the equation $g = \frac{GM_{source}}{r^2}$ to calculate the magnitude of the gravitational field strength on Saturn.

$$g_{Saturn} = \frac{Gm_{Saturn}}{(r_{Saturn})^2}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{N \bullet m^2}{kg^{\cancel{2}}}\right)(5.68 \times 10^{26}\ \cancel{kg})}{\left(6.03 \times 10^7\ m\right)^2}$$

$$= 10.42\ N/kg$$

The weight of the astronaut is directed toward the centre of Saturn. So use the scalar form of the equation $\vec{F}_g = m\,\vec{g}$.

$$F_g = m_a g_{Saturn}$$

$$= \left(60.0\ \cancel{kg}\right)\left(10.42\ \frac{N}{\cancel{kg}}\right)$$

$$= 6.25 \times 10^2\ N$$

$$\vec{F}_g = 6.25 \times 10^2\ N\ [\text{toward centre of Saturn}]$$

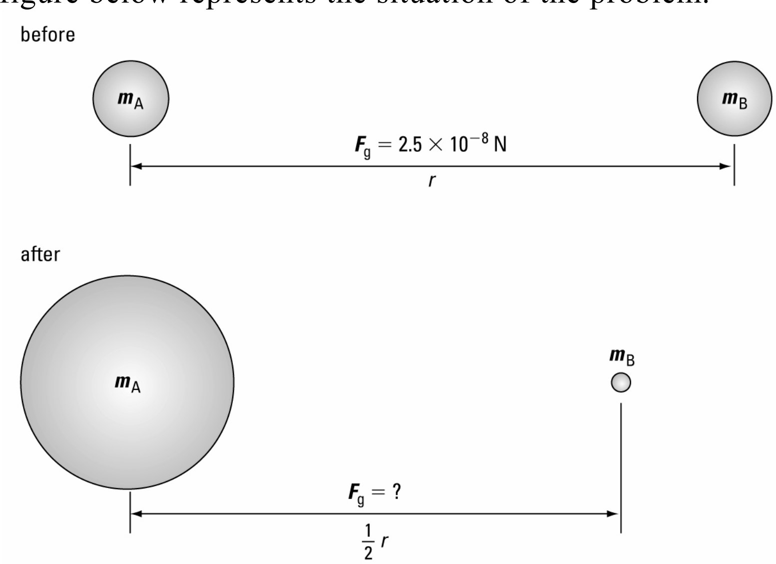
Paraphrase

On Saturn, the astronaut has a true weight of 6.25×10^2 N [toward centre of Saturn].

8. *Analysis and Solution*

From Newton's law of gravitation, $F_g \propto m_A m_B$ and $F_g \propto \frac{1}{r^2}$.

The figure below represents the situation of the problem.



$$F_g \propto (8m_A)\left(\frac{1}{4}m_B\right) \quad \text{and} \quad F_g \propto \frac{1}{\left(\frac{1}{2}r\right)^2}$$

$$\propto (8)\left(\frac{1}{4}\right) m_A m_B \qquad \propto 2^2\left(\frac{1}{r^2}\right)$$

$$\propto 2m_A m_B \qquad \propto 4\left(\frac{1}{r^2}\right)$$

Calculate the factor change of F_g.

2 × 4= 8

Calculate F_g.

$8F_g = 8 \times (2.5 \times 10^{-8}\ \text{N})$

$= 2.0 \times 10^{-7}$ N

The new magnitude of the gravitational force will be 2.0×10^{-7} N.

9. (a) ***Given***

$m_a = 65$ kg

$\vec{a} = 0\ \text{m/s}^2$

$m_{Mars} = 6.42 \times 10^{23}$ kg $\quad r_{Mars} = 3.40 \times 10^6$ m

Required

reading on scale (w)

Analysis and Solution

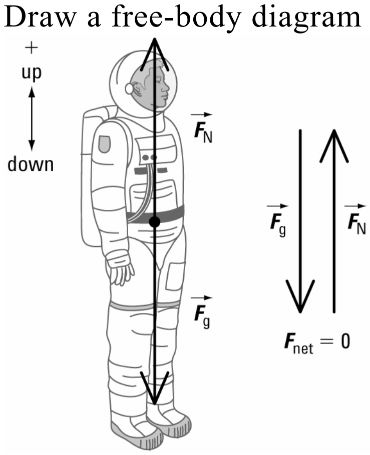
Use the equation $g = \dfrac{GM_{source}}{r^2}$ to calculate the magnitude of the gravitational acceleration on Mars.

$$g_{Mars} = \frac{Gm_{Mars}}{(r_{Mars})^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^{\not 2}}\right)(6.42\times10^{23}\ \not{\text{kg}})}{\left(3.40\times10^6\ \text{m}\right)^2}$$

$$= 3.70\ \text{m/s}^2$$

Draw a free-body diagram for the astronaut.



The astronaut is not accelerating.

So in both the horizontal and vertical directions, $\vec{F}_{net} = 0$ N.

For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$

$$0 = F_g + F_N$$

$$F_N = F_g$$

$$= mg$$

$$= (65\ \text{kg})(3.70\ \text{m/s}^2)$$

$$= 2.41 \times 10^2\ \text{N}$$

$\vec{F}_N = 2.41 \times 10^2$ N [up]

The reading on the scale is equal to the magnitude of the apparent weight. So use the scalar form of the equation $\vec{w} = -\vec{F}_N$.

$$\begin{aligned} w &= F_N \\ &= 2.4 \times 10^2 \text{ N} \end{aligned}$$

Paraphrase

The reading on the scale will be 2.4×10^2 N.

(b) ***Given***

$m_a = 65$ kg

$\vec{a} = 7.2$ m/s^2 [up]

$m_{Mars} = 6.42 \times 10^{23}$ kg $\quad r_{Mars} = 3.40 \times 10^6$ m

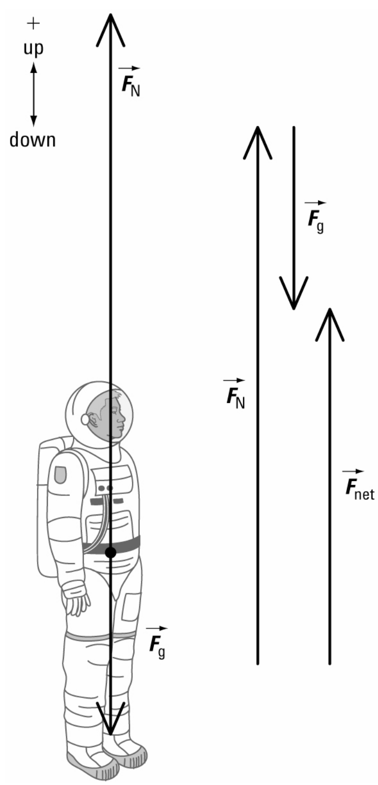
$\vec{F}_g = 2.41 \times 10^2$ N [down] from part (a)

Required

reading on scale (w)

Analysis and Solution

Draw a free-body diagram for the astronaut.



The astronaut is not accelerating left or right.

So in the horizontal direction, $\vec{F}_{net} = 0$ N.

For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$

$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$ma = F_g + F_N$

$F_N = ma - F_g$

$= (65 \text{ kg})(7.2 \text{ m/s}^2) - (-2.41 \times 10^2 \text{ N})$

$= (65 \text{ kg})(7.2 \text{ m/s}^2) + 2.41 \times 10^2 \text{ N}$

$= 7.09 \times 10^2 \text{ N}$

$\vec{F}_N = 7.09 \times 10^2 \text{ N [up]}$

The reading on the scale is equal to the magnitude of the apparent weight. So use the scalar form of the equation $\vec{w} = -\vec{F}_N$.

$w = F_N$

$= 7.1 \times 10^2 \text{ N}$

Paraphrase

The reading on the scale will be 7.1×10^2 N.

(c) ***Given***

$m_a = 65 \text{ kg}$

$\vec{a} = 3.6 \text{ m/s}^2 \text{ [down]}$

$m_{Mars} = 6.42 \times 10^{23} \text{ kg}$ $\quad r_{Mars} = 3.40 \times 10^6 \text{ m}$

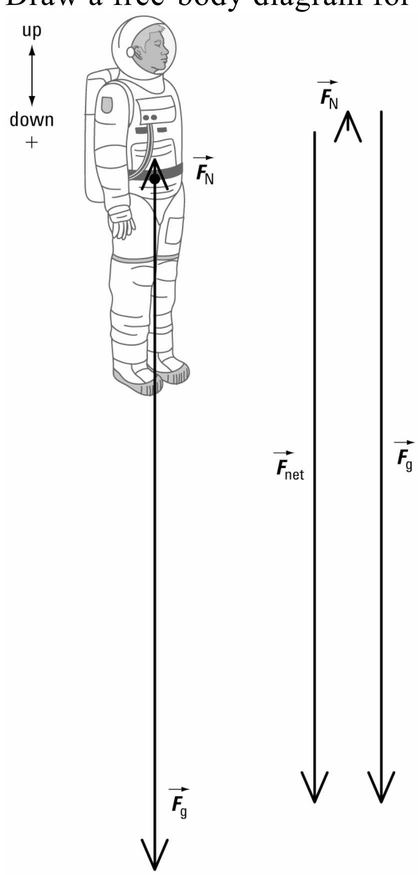
$\vec{F}_g = 2.41 \times 10^2 \text{ N [down]}$ from part (a)

Required

reading on scale (w)

Analysis and Solution

Draw a free-body diagram for the astronaut.



The astronaut is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the astronaut.

$$\vec{F}_{net} = \vec{F}_g + \vec{F}_N$$
$$F_{net} = F_g + F_N$$

Apply Newton's second law.

$$\begin{aligned} ma &= F_g + F_N \\ F_N &= ma - F_g \\ &= (65 \text{ kg})(3.6 \text{ m/s}^2) - 2.41 \times 10^2 \text{ N} \\ &= -6.8 \text{ N} \\ \vec{F}_N &= 6.8 \text{ N [up]} \end{aligned}$$

The reading on the scale is equal to the magnitude of the apparent weight. So use the scalar form of the equation $\vec{w} = -\vec{F}_N$.

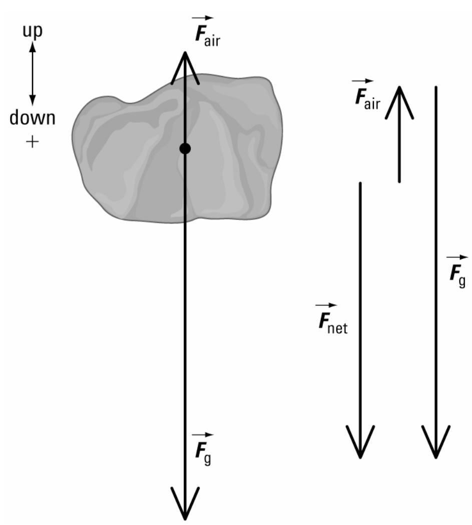
$$\begin{aligned} w &= F_N \\ &= 6.8 \text{ N} \end{aligned}$$

Paraphrase
The reading on the scale will be 6.8 N.

10. (a) ***Given***
$m = 50$ kg $\quad d = 500$ m
magnitude of $\vec{F}_{air} = 125$ N $\quad \vec{g} = 9.81 \text{ m/s}^2$ [down]

Required
average acceleration of the rock ($\vec{a}_{ave}$)

Analysis and Solution
Draw a free-body diagram for the rock.



The rock is not accelerating left or right.
So in the horizontal direction, $\vec{F}_{net} = 0$ N.
For the vertical direction, write an equation to find the net force on the rock.

$\vec{F}_{net} = \vec{F}_g + \vec{F}_{air}$

$F_{net} = F_g + F_{air}$

Apply Newton's second law.

$$ma_{ave} = mg + F_{air}$$

$$a_{ave} = g + \frac{F_{air}}{m}$$

$$= 9.81 \text{ m/s}^2 + \left(\frac{-125 \text{ N}}{50 \text{ kg}}\right)$$

$$= 9.81 \text{ m/s}^2 - \frac{125 \cancel{\text{kg}} \bullet \frac{\text{m}}{\text{s}^2}}{50 \cancel{\text{kg}}}$$

$$= 7.3 \text{ m/s}^2$$

$$\vec{a}_{ave} = 7.3 \text{ m/s}^2 \text{ [down]}$$

Paraphrase

The average acceleration of the rock is 7.3 m/s^2 [down].

(b) ***Given***

$m = 50$ kg

magnitude of $\vec{F}_{air} = 125$ N

$\vec{a}_{ave} = 7.31$ m/s^2 [down] from part (a)

$d = 500$ m

$\vec{g} = 9.81$ m/s^2 [down]

Required

time taken to reach the water (Δt)

Analysis and Solution

Calculate the time interval.

$$d = \left(\frac{1}{2}\right) a_{ave}(\Delta t)^2$$

$$(\Delta t)^2 = \frac{2d}{a_{ave}}$$

$$\Delta t = \sqrt{\frac{2d}{a_{ave}}}$$

$$= \sqrt{\frac{2(500 \text{ m})}{7.31 \text{ m/s}^2}}$$

$$\Delta t = 12 \text{ s}$$

Paraphrase

The rock takes 12 s to reach the water.

(c) ***Given***

$m = 50$ kg

magnitude of $\vec{F}_{air} = 125$ N

$d = 500$ m

$\vec{g} = 9.81$ m/s^2 [down]

Required

true weight of rock ($\vec{F}_g$)

Analysis and Solution

The weight of the rock is directed toward Earth's centre. So use the scalar form of the equation $\vec{F}_g = m\vec{g}$.

$$\begin{aligned} F_g &= mg \\ &= (50\ \text{kg})(9.81\ \text{m/s}^2) \\ &= 4.9 \times 10^2\ \text{N} \\ \vec{F}_g &= 4.9 \times 10^2\ \text{N [toward Earth's centre]} \end{aligned}$$

Paraphrase

The rock has a true weight of 4.9×10^2 N [toward Earth's centre].

(d) If the rock did not experience any air resistance, its apparent weight would be zero. However, in this problem, air resistance acts on the rock. So the rock has an apparent weight.

Extensions

11. During a normal space flight, astronauts exercise for about 30 min every day. An astronaut in a spaceship orbiting Earth is in free fall so the exercises are necessary to counteract the deconditioning of the human body caused by a free fall orbit.

On Earth, the lower torso and legs have to carry the weight of the human body. In a spaceship, an astronaut floats around and the legs are basically not used at all. As a result, the lower back and leg muscles become atrophied and the bones in these areas begin to demineralize, much like a limb in a cast. If a space mission is of short duration, these degenerative processes are just starting. But on missions of long duration, the degeneration is a serious threat to the health of the astronauts. So resistance exercises to maintain muscle mass and bone strength are required for all crewmembers. The exercises help prepare astronauts for their return to Earth, so that their bodies can support their actual weight. The fitness equipment on board the Shuttle includes a treadmill, a bicycle ergometer, and bungee rubber bands.

12. Early in World War II, a research team led by Frederick Banting discovered that fighter pilots frequently crashed as they pulled out of steep turns because the acceleration causes blood to move away from the brain and heart and move toward the legs and feet instead. A team led by Dr. Wilbur Franks first developed overalls made of two layers of rubber with water in between, which laced tight against the pilot's body. Dr. Franks' team later developed the FFS Mk III, an air-inflated, zippered version that led directly to the first anti-gravity suit to go into war service. Modern *g*-suits use the same physiological principle applied by Dr. Franks. Such suits are used to maintain the blood supply to the brain and heart during periods of rapid acceleration during space flights.

