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Problem 12.1 In 1967, the International Committee of Weights and Measures defined one second to be the time required for 9,192,631,770 cycles of the transition between two quantum states of the cesium-133 atom. Express the number of cycles in two seconds to four significant digits.

Solution: The number of cycles in two seconds is $2(9{,}192{,}631{,}770) = 18{,}385{,}263{,}540$.

Expressed to four significant digits, this is $18{,}390{,}000{,}000$ or 1.839E10 cycles.

18,390,000,000 or 1.839E10 cycles.

Problem 12.2 The base of natural logarithms is $e = 2.71828183\ldots$. (a) Express e to three significant digits. (b) Determine the value of e^2 to three significant digits. (c) Use the value of e you obtained in part (a) to determine the value of e^2 to three significant digits.

[Comparing the answers of parts (b) and (c) demonstrates the hazard of using rounded-off values in calculations.]

Solution:

(a) The rounded-off value is $e = 2.72$.
(b) $e^2 = 7.38905610\ldots$, so to three significant digits it is $e^2 = 7.39$.
(c) Squaring the three-digit number we obtained in part (a) and expressing it to three significant digits, we obtain $e^2 = 7.40$.

(a) $e = 2.72$. (b) $e^2 = 7.39$. (c) $e^2 = 7.40$.

Problem 12.3 The base of natural logarithms (see Problem 12.2) is given by the infinite series

$$e = 2 + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \cdots .$$

Its value can be approximated by summing the first few terms of the series. How many terms are needed for the approximate value rounded off to five digits to be equal to the exact value rounded off to five digits?

Solution: The exact value rounded off to five significant digits is $e = 2.7183$. Let N be the number of terms summed. We obtain the results

N	Sum
1	2
2	2.5
3	2.666...
4	2.708333...
5	2.71666...
6	2.7180555...
7	2.7182539...

We see that summing seven terms gives the rounded-off value 2.7183.

Seven.

Problem 12.4 The opening in the soccer goal is 24 ft wide and 8 ft high, so its area is $24\ \text{ft} \times 8\ \text{ft} = 192\ \text{ft}^2$. What is its area in m^2 to three significant digits?



Solution: Converting units (notice the procedure used to convert ft^2 to m^2), the area is

$$192\ \text{ft}^2 = 192\ \text{ft}^2\left(\frac{1\ \text{m}}{3.281\ \text{ft}}\right)^2 = 17.8\ \text{m}^2.$$

17.8 m^2.

Problem 12.5 In 2020, teams from China and Nepal, based on their independent measurements using GPS satellites, determined that the height of Mount Everest is 8848.86 meters. Determine the height of the mountain to three significant digits (a) in kilometers; (b) in miles.

Solution:

(a) The height of the mountain in kilometers to three significant digits is

$$8848.86\ \text{m} = 8848.86\ \text{m}\left(\frac{1\ \text{km}}{1000\ \text{m}}\right) = 8.85\ \text{km}.$$

(b) Its height in miles to three significant digits is

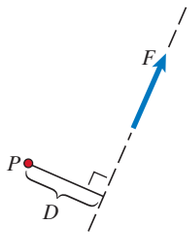
$$8848.86\ \text{m} = 8848.86\ \text{m}\left(\frac{3.281\ \text{ft}}{1\ \text{m}}\right)\left(\frac{1\ \text{mi}}{5280\ \text{ft}}\right) = 5.50\ \text{mi}.$$

(a) 8.85 km. (b) 5.50 mi.

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Problem 12.6 The distance $D = 6$ in (inches). The magnitude of the moment of the force $F = 12$ lb (pounds) about point P is defined to be the product $M_P = FD$. What is the value of M_P in N-m (newton-meters)?



Solution: The value of M_P is

$$\begin{aligned} M_P &= FD \\ &= (12 \text{ lb})(6 \text{ in}) \\ &= 72 \text{ lb-in.} \end{aligned}$$

Converting units, the value of M_P in N-m is

$$72 \text{ lb-in} = 72 \text{ lb-in}\left(\frac{1 \text{ N}}{0.2248 \text{ lb}}\right)\left(\frac{1 \text{ m}}{39.37 \text{ in}}\right) = 8.14 \text{ N-m.}$$

8.14 N-m.

Problem 12.7 The length of this Boeing 737 is 110 ft 4 in and its wingspan is 117 ft 5 in. Its maximum takeoff weight is 154,500 lb. Its maximum range is 3365 nautical miles. Express each of these quantities in SI units to three significant digits.



Solution: Because 1 ft = 12 in, the length in meters is

$$\left(110 + \frac{4}{12} \text{ ft}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 33.6 \text{ m.}$$

In the same way, the wingspan in meters is

$$\left(117 + \frac{5}{12} \text{ ft}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 35.8 \text{ m.}$$

The weight in newtons is

$$(154{,}500 \text{ lb})\left(\frac{4.448 \text{ N}}{1 \text{ lb}}\right) = 687{,}000 \text{ N.}$$

One nautical mile is 1852 meters. Therefore, the range in meters is

$$(3365 \text{ nautical miles})\left(\frac{1852 \text{ m}}{1 \text{ nautical mile}}\right) = 6.23\text{E}6 \text{ m.}$$

Length = 33.6 m, wingspan = 35.8 m,
weight = 687 kN, range = 6230 km.

Problem 12.8 The maglev (magnetic levitation) train from Shanghai to the airport at Pudong reaches a speed of 430 km/h. Determine its speed (a) in mi/h; (b) in ft/s.

Solution:

(a) The speed in miles per hour is

$$430 \text{ km/h} = 430 \frac{\text{km}}{\text{h}}\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right)\left(\frac{1 \text{ mi}}{5280 \text{ ft}}\right) = 267 \text{ mi/h.}$$

(b) The speed in feet per second is

$$430 \text{ km/h} = 430 \frac{\text{km}}{\text{h}}\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right)\left(\frac{1 \text{ hr}}{3600 \text{ s}}\right) = 392 \text{ ft/s.}$$

(a) 267 mi/h; (b) 392 ft/s.



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Problem 12.9 In the 2006 Winter Olympics, the men's 15-km cross-country skiing race was won by Andrus Veerpalu of Estonia in a time of 38 minutes, 1.3 seconds. Determine his average speed (the distance traveled divided by the time required) to three significant digits (a) in km/h; (b) in mi/h.

Solution:

(a) His time in the race in hours was

$$38 \text{ mins}\left(\frac{1 \text{ h}}{60 \text{ mins}}\right) + 1.3 \text{ s}\left(\frac{1 \text{ h}}{3600 \text{ s}}\right) = 0.634 \text{ h}.$$

His average speed in kilometers per hour was

$$\frac{15 \text{ km}}{0.634 \text{ h}} = 23.7 \text{ km/h}.$$

(b) His average speed in miles per hour was

$$23.7 \text{ km/h} = 23.7 \frac{\text{km}}{\text{h}}\left(\frac{0.6214 \text{ mi}}{1 \text{ km}}\right) = 14.7 \text{ mi/h}.$$

(a) 23.7 km/h; (b) 14.7 mi/h.

Problem 12.10 The Porsche's engine exerts 229 ft-lb (foot-pounds) of torque at 4600 rpm. Determine the value of the torque in N-m (newton-meters).

Solution: The torque in newton-meters is

$$229 \text{ ft-lb} = 229 \text{ ft-lb}\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)\left(\frac{4.448 \text{ N}}{1 \text{ lb}}\right) = 310 \text{ N-m}.$$

310 N-m.



Problem 12.10

Problem 12.11 The *kinetic energy* of the man in Practice Example 12.1 is defined by $\frac{1}{2}mv^2$, where m is his mass and v is his velocity. The man's mass is 68 kg and he is moving at 6 m/s, so his kinetic energy is $\frac{1}{2}(68 \text{ kg})(6 \text{ m/s})^2 = 1224 \text{ kg-m}^2/\text{s}^2$. What is his kinetic energy in US customary units?

Solution: The kinetic energy in US customary units is

$$1224 \text{ kg-m}^2/\text{s}^2 = 1224 \text{ kg-m}^2/\text{s}^2\left(\frac{1 \text{ slug}}{14.59 \text{ kg}}\right)\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right)^2$$
$$= 903 \text{ slug-ft}^2/\text{s}^2.$$

903 slug-ft^2/s^2.

Problem 12.12 The acceleration due to gravity at sea level in SI units is $g = 9.81 \text{ m/s}^2$. By converting units, use this value to determine the acceleration due to gravity at sea level in US customary units.

Solution: The acceleration due to gravity in US customary units is

$$9.81 \text{ m/s}^2 = 9.81 \text{ m/s}^2\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right) = 32.2 \text{ ft/s}^2.$$

32.2 ft/s^2.

Problem 12.13 The value of the universal gravitational constant in SI units is $G = 6.67\text{E}{-11} \text{ m}^3/\text{kg-s}^2$. Use this value and convert units to determine the value of G in US customary units.

Solution: The value of G in US customary units is

$$G = 6.67\text{E}{-11} \frac{\text{m}^3}{\text{kg-s}^2}\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right)^3\left(\frac{14.59 \text{ kg}}{1 \text{ slug}}\right) = 3.44\text{E}{-8} \text{ ft}^3/\text{slug-s}^2.$$

$G = 3.44\text{E}{-8}$ ft^3/slug-s^2.

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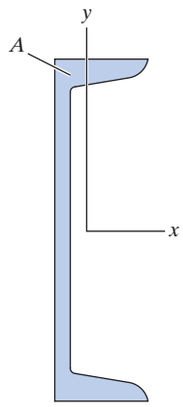
Problem 12.14 The density (mass per unit volume) of aluminum is 2700 kg/m^3. Determine its density in slug/ft^3.

Solution: Converting units, the density is

$$2700 \text{ kg/m}^3 = 2700 \text{ kg/m}^3\left(\frac{0.0685 \text{ slug}}{1 \text{ kg}}\right)\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)^3$$
$$= 5.24 \text{ slug/ft}^3.$$

$\boxed{5.24 \text{ slug/ft}^3.}$

Problem 12.15 The cross-sectional area of the C12×30 American Standard Channel steel beam is $A = 8.81$ in^2. What is its cross-sectional area in mm^2?



Solution: The area in square millimeters is

$$A = 8.81 \text{ in}^2\left(\frac{25.40 \text{ mm}}{1 \text{ in}}\right)^2 = 5680 \text{ mm}^2.$$

$\boxed{A = 5680 \text{ mm}^2.}$

Problem 12.16 A pressure transducer measures a value of 300 lb/in^2. Determine the value of the pressure in pascals. A pascal (Pa) is one newton per square meter.

Solution: The pressure in pascals is

$$300 \text{ lb/in}^2\left(\frac{4.448 \text{ N}}{1 \text{ lb}}\right)\left(\frac{1 \text{ in}}{0.02540 \text{ m}}\right)^2 = 2.07\text{E}6 \text{ N/m}^2$$
$$= 2.07\text{E}6 \text{ Pa}.$$

$\boxed{2.07\text{E}6 \text{ Pa}.}$

Problem 12.17 A horsepower is 550 ft-lb/s. A watt is 1 N-m/s. Determine how many watts are generated by the engines of the passenger jet if they are producing 7000 horsepower.



Solution: The power in watts is

$$7000 \text{ horsepower}\left(\frac{550 \text{ ft-lb/s}}{1 \text{ horsepower}}\right)\left(\frac{4.448 \text{ N}}{1 \text{ lb}}\right)\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right) = 5.22\text{E}6 \text{ N-m/s}$$
$$= 5.22\text{E}6 \text{ watts}.$$

$\boxed{5.22\text{E}6 \text{ watts}.}$

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Problem 12.18 A typical speed of the head of a driver on the PGA Tour is 100 miles per hour. Determine the speed in ft/s, m/s, and km/h.



Source: Courtesy of Takanakai/123RF.

Solution: The speed in ft/s is

$$100 \text{ mi/h} = 100 \text{ mi/h}\left(\frac{5280 \text{ ft}}{1 \text{ mi}}\right)\left(\frac{1 \text{ h}}{3600 \text{ s}}\right) = 147 \text{ ft/s}.$$

The speed in m/s is

$$147 \text{ ft/s} = 147 \text{ ft/s}\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 44.7 \text{ m/s}.$$

The speed in km/h is

$$100 \text{ mi/h} = 100 \text{ mi/h}\left(\frac{1.609 \text{ km}}{1 \text{ mi}}\right) = 161 \text{ km/h}.$$

$\boxed{147 \text{ ft/s}, 44.7 \text{ m/s}, 161 \text{ km/h}.}$

Problem 12.19 In 2000, a carbon nanotube was shown to support a tensile stress of 63 GPa (gigapascals). A pascal is 1 N/m^2. Determine the value of this tensile stress in lb/in^2. (This is the amount of force in pounds that could theoretically be supported in tension by a bar of this material with a cross-sectional area of one square inch.)

Solution: Converting units, the tensile stress is

$$\begin{aligned} 63\text{E}9 \text{ N/m}^2 &= 63\text{E}9 \frac{\text{N}}{\text{m}^2}\left(\frac{1 \text{ lb}}{4.448 \text{ N}}\right)\left(\frac{1 \text{ m}}{39.37 \text{ in}}\right)^2 \\ &= 9.14\text{E}6 \text{ lb/in}^2. \end{aligned}$$

$\boxed{9.14\text{E}6 \text{ lb/in}^2.}$

Problem 12.20 In dynamics, the moments of inertia of an object are expressed in units of $(\text{mass}) \times (\text{length})^2$. If one of the moments of inertia of a particular object is 600 slug-ft^2, what is its value in kg-m^2?

Solution: Converting units,

$$\begin{aligned} 600 \text{ slug-ft}^2 &= 600 \text{ slug-ft}^2\left(\frac{14.59 \text{ kg}}{1 \text{ slug}}\right)\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)^2 \\ &= 813 \text{ kg-m}^2. \end{aligned}$$

$\boxed{813 \text{ kg-m}^2.}$

Problem 12.21 The airplane's drag coefficient C_D is defined by

$$C_D = \frac{D}{S\frac{1}{2}\rho v^2},$$

where D is the drag force exerted on the airplane by the air, S is the wing area, ρ is the density (mass per unit volume) of the air, and v is the magnitude of the airplane's velocity. At the instant shown, the drag force $D = 5300$ N, the wing area is $S = 100 \text{ m}^2$, the air density is $\rho = 1.226 \text{ kg/m}^3$, and the velocity is $v = 60$ m/s. (a) What is the value of the drag coefficient? (b) Determine the values of D, S, ρ, and v in terms of US customary units and use them to calculate the drag coefficient.



Source: Courtesy of Fasttailwind/Shutterstock.

Solution:

(a) The drag coefficient is

$$\begin{aligned} C_D &= \frac{D}{S\frac{1}{2}\rho v^2} \\ &= \frac{5300 \text{ N}}{(100 \text{ m}^2)\frac{1}{2}(1.226 \text{ kg/m}^3)(60 \text{ m/s})^2} \\ &= 0.0240. \end{aligned}$$

(b) Converting units, the drag force is

$$D = 5300 \text{ N}\left(\frac{0.2248 \text{ lb}}{1 \text{ N}}\right) = 1190 \text{ lb},$$

the reference area is

$$S = 100 \text{ m}^2\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right)^2 = 1080 \text{ ft}^2,$$

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12.21 (*Continued*)

the density is

$$\rho = 1.226 \text{ kg/m}^3\left(\frac{0.0685 \text{ slug}}{1 \text{ kg}}\right)\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)^3$$
$$= 0.00238 \text{ slug/ft}^3,$$

and the velocity is

$$v = 60 \text{ m/s}\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right) = 197 \text{ ft/s}.$$

Therefore, the drag coefficient is

$$C_D = \frac{D}{S\frac{1}{2}\rho v^2}$$
$$= \frac{1190 \text{ lb}}{(1080 \text{ ft}^2)\frac{1}{2}(0.00238 \text{ slug/ft}^3)(197 \text{ ft/s})^2}$$
$$= 0.0240.$$

(*a*) $C_D = 0.0240$. (b) $D = 1190$ lb, $S = 1080$ ft^2, $\rho = 0.00238$ slug/ft^3, $v = 197$ ft/s, $C_D = 0.0240$.

Problem 12.22 A person has a mass of 72 kg. (a) What is their weight at sea level in newtons? (b) What is their mass in slugs? (c) What is their weight at sea level in pounds?

Solution:

(a) From Eq. (12.6), their weight is

$$W = mg$$
$$= (72 \text{ kg})(9.81 \text{ m/s}^2)$$
$$= 706 \text{ N}.$$

(b) Using a unit conversion factor, their mass in slugs is

$$m = (72 \text{ kg})\left(\frac{0.0685 \text{ slug}}{1 \text{ kg}}\right)$$
$$= 4.93 \text{ slugs}.$$

(c) Using Eq. (12.6), their weight is

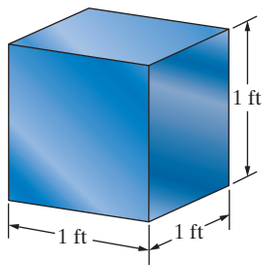
$$W = mg$$
$$= (4.93 \text{ slugs})(32.2 \text{ ft/s}^2)$$
$$= 159 \text{ lb}.$$

Or we could use a conversion factor to convert their weight from newtons to pounds, obtaining

$$W = (706 \text{ N})\left(\frac{0.2248 \text{ lb}}{1 \text{ N}}\right)$$
$$= 159 \text{ lb}.$$

(a) 706 N. (b) 4.93 slugs. (c) 159 lb.

Problem 12.23 The 1 ft × 1 ft × 1 ft cube of iron weighs 490 lb at sea level. Determine the weight in newtons of a 1 m × 1 m × 1 m cube of the same material at sea level.



Solution: First we determine the volume of the 1 m × 1 m × 1m cube in terms of ft^3:

$$1 \text{ m}^3 = 1 \text{ m}^3\left(\frac{3.281 \text{ ft}}{1 \text{ m}}\right)^3 = 35.32 \text{ ft}^3.$$

From this result, we know that the 1 m × 1 m × 1m cube of material weighs

$$(35.32 \text{ ft}^3)(490 \text{ lb/ft}^3) = 17{,}310 \text{ lb}.$$

Now we convert this weight to newtons:

$$17{,}310 \text{ lb} = 17{,}310 \text{ lb}\left(\frac{4.448 \text{ N}}{1 \text{ lb}}\right) = 76{,}980 \text{ N}.$$

77.0 kN.

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Problem 12.24 The area of the Pacific Ocean is 64,186,000 square miles and its average depth is 12,925 ft. Assume that the weight per unit volume of ocean water is 64 lb/ft^3. Determine the mass of the Pacific Ocean (a) in slugs; (b) in kilograms.

Solution: The volume of the ocean is

$$V = (64{,}186{,}000 \text{ mi}^2)\left(\frac{5280 \text{ ft}}{1 \text{ mi}}\right)^2 (12{,}925 \text{ ft})$$
$$= 2.31\text{E}19 \text{ ft}^3.$$

(a) The mass of the ocean in slugs is

$$m = \rho V = \left(\frac{64 \text{ lb/ft}^3}{32.2 \text{ ft/s}^2}\right)(2.31\text{E}19 \text{ ft}^3)$$
$$= 4.60\text{E}19 \text{ slugs}.$$

(b) Its mass in kilograms is

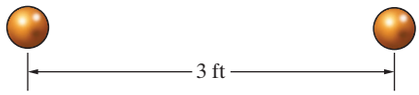
$$m = (4.60\text{E}19 \text{ slugs})\left(\frac{14.59 \text{ kg}}{1 \text{ slug}}\right)$$
$$= 6.71\text{E}20 \text{ kg}.$$

(a) 4.60E19 slugs. (b) 6.71E20 kg.

Problem 12.25 Two oranges weighing 8 oz (ounces) each at sea level are 3 ft apart. (a) What is the magnitude of the gravitational force F they exert on each other? (b) If a stationary object of mass m is subjected to a constant force F and no other forces, the time required for it to reach a speed v is

$$t = \frac{mv}{F}.$$

If you subjected one of the oranges to a constant force equal to the force you determined in part (a) and no other forces, how long would it take to reach a speed of 1 ft/s?



Solution:

(a) One pound equals 16 ounces, so the weight of each orange is $W = 0.5$ lb and its mass is

$$m = \frac{W}{g} = \frac{0.5 \text{ lb}}{32.2 \text{ ft/s}^2} = 0.0155 \text{ slugs}.$$

In US customary units, the universal gravitational constant is

$$G = 3.44\text{E}{-8} \text{ ft}^3/\text{slug-s}^2.$$

From Eq. (12.1), the gravitational force the oranges exert on each other is

$$F = \frac{Gm^2}{r^2} = \frac{(3.44\text{E}{-8} \text{ ft}^3/\text{slug-s}^2)(0.0155 \text{ slugs})}{(3 \text{ ft})^2}$$
$$= 9.22\text{E}{-13} \text{ lb}.$$

(b) From the given equation, the time required is

$$t = \frac{mv}{F} = \frac{(0.0155 \text{ slugs})(1 \text{ ft/s})}{9.22\text{E}{-13} \text{ lb}}$$
$$= 1.68\text{E}10 \text{ s (534 years)}.$$

(a) $F = 9.22\text{E}{-13}$ lb; (b) $t = 1.68\text{E}10$ s (534 years).

Problem 12.26 A person weighs 180 lb at sea level. The radius of the Earth is 3960 mi. What force is exerted on the person by the gravitational attraction of the Earth if he is in a space station in orbit 200 mi above the surface of the Earth?

Solution: The person's weight at sea level is $W = mg = 180$ lb. The Earth's radius is $R_E = 3960$ mi. The radius of the space station's circular orbit in miles is $r = R_E + 200$ mi $= 4160$ mi. From Eqs. (12.5) and (12.6), the person's weight, the force exerted on him by gravity, is

$$W = (180 \text{ lb})\left(\frac{R_E}{r}\right)^2 = (180 \text{ lb})\left(\frac{3960 \text{ mi}}{4160 \text{ mi}}\right)^2$$
$$= 163 \text{ lb}.$$

(It is normally necessary to convert terms into base units when applying equations. In this case, why didn't we convert R_E and r from miles into feet? The ratio of two values describing the same physical quantity, in this case two distances, is the same no matter what units are used to express them.)

163 lb.

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Problem 12.27 The acceleration due to gravity on the surface of the Moon is 1.62 m/s^2. The Moon's radius is $R_M = 1738$ km. (a) What is the weight in newtons on the surface of the Moon of an object that has a mass of 10 kg? (b) Using the approach described in Practice Example 12.6, determine the force exerted on the object by the gravity of the Moon if the object is located 1738 km above the Moon's surface.

Solution:

(a) To solve this problem we must adapt equations that were stated for the Earth. We write
Eq. (12.6) for the weight of an object at sea level on Earth as

$$W_M = mg_M,$$

where $g_M = 1.62$ m/s^2 is the acceleration due to gravity at the Moon's surface and W_M is the weight at the surface of an object of mass m. Then the weight of a 10-kg object is

$$W_M = mg_M = (10 \text{ kg})(1.62 \text{ m/s}^2) = 16.2 \text{ N}.$$

(b) Adapting Eq. (12.5) to the Moon, the weight of an object of mass m that is a distance r from the center of the Moon is

$$W_M = mg_M \frac{R_M}{r^2}.$$

For the distance given, the mass of the 10-kg object is

$$W_M = mg_M \frac{R_M{}^2}{r^2} = (10 \text{ kg})(1.62 \text{ m/s}^2)\frac{(1738 \text{ km})^2}{(1738 \text{ km} + 1738 \text{ km})^2} = 4.05 \text{ N}.$$

(a) 16.2 N; (b) 4.05 N.

Problem 12.28 If an object is near the surface of the Earth, the variation of its weight with distance from the center of the Earth can often be neglected. The acceleration due to gravity at sea level is $g = 9.81$ m/s^2. The radius of the Earth is 6370 km. The weight of an object at sea level is mg, where m is its mass. At what height above the surface of the Earth does the weight of the object decrease to $0.99\,mg$?

Solution: Let h denote the height of an object of mass m above the surface of the Earth, so that the distance of the object above the center of the Earth is $r = R_E + h$. The object's weight at sea level is mg. Its weight at the distance r is given by Eq. (12.5), so we assume that

$$0.99\,mg = mg\frac{R_E{}^2}{r^2} = mg\frac{R_E{}^2}{(R_E + h)^2}.$$

Using the given value for R_E and solving the equation

$$0.99 = \frac{R_E{}^2}{(R_E + h)^2}$$

for h, we obtain $h = 32.1$ km (105,000 ft).

32.1 km.

Problem 12.29 A person has a mass of 72 kg. The radius of the Earth is 6370 km. (a) What is his weight at sea level in newtons and in pounds? (b) If he is in a space station 420 km above the surface of the Earth, what force is exerted on him by the Earth's gravitational attraction in newtons and in pounds?

Solution:

(a) From Eq. (12.6), his weight at sea level is

$$W = mg = (72 \text{ kg})(9.81 \text{ m/s}^2) = 706 \text{ N}.$$

Using a conversion factor, his weight at sea level in pounds is

$$W = 706 \text{ N}\left(\frac{0.2248 \text{ lb}}{1 \text{ N}}\right) = 159 \text{ lb}.$$

(b) To apply Eq. (12.5), we need his distance from the center of the Earth:

$$r = 6370 \text{ km} + 420 \text{ km} = 6790 \text{ km}.$$

Then from Eq. (12.5), the gravitational force on him is

$$W = mg\frac{R_E{}^2}{r^2} = (72 \text{ kg})(9.81 \text{ m/s}^2)\frac{(6{,}370{,}000 \text{ m})^2}{(6{,}790{,}000 \text{ m})^2} = 622 \text{ N}.$$

The force on him in pounds is

$$W = 622 \text{ N}\left(\frac{0.2248 \text{ lb}}{1 \text{ N}}\right) = 140 \text{ lb}.$$

(a) 706 N, 159 lb. (b) 622 N, 140 lb.

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Problem 12.30 If you model the Earth as a homogeneous sphere, at what height above sea level does your weight decrease to one-half of its value at sea level? Determine the answer (a) in kilometers; (b) in miles. (The radius of the Earth is 6370 km.)

Solution:

(a) Your weight will decrease to 0.5 times its value at sea level at the height at which the Earth's acceleration due to gravity decreases to 0.5 times its value at sea level. From Eq. (12.3), the acceleration due to gravity at a distance r from the center of the Earth is

$$a = \frac{Gm_E}{r^2},$$

where m_E is the Earth's mass. The acceleration due to gravity at sea level is

$$g = \frac{Gm_E}{R_E^2}, \qquad (1)$$

where R_E is the Earth's radius. Let H be the height above sea level at which the acceleration due to gravity equals $0.5g$. That is,

$$0.5g = \frac{Gm_E}{(R_E + H)^2}.$$

Dividing this equation by Eq. (1) yields

$$0.5 = \frac{R_E^2}{(R_E + H)^2}.$$

Solving for H, we obtain

$$\begin{aligned} H &= \left(\frac{1}{\sqrt{0.5}} - 1\right)R_E \\ &= \left(\frac{1}{\sqrt{0.5}} - 1\right)(6370 \text{ km}) \\ &= 2640 \text{ km}. \end{aligned}$$

(b) In terms of miles, the value of H is

$$\begin{aligned} H &= 2640 \text{ km}\left(\frac{1 \text{ mi}}{1.609 \text{ km}}\right) \\ &= 1640 \text{ mi}. \end{aligned}$$

(a) 2640 km. (b) 1640 mi.

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