Introduction to Engineering Analysis 5th edition Hagen Solutions Manual

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Solutions Manual

for

Introduction to Engineering Analysis

5th Edition

by

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Introduction to Engineering Analysis 5th edition Hagen Solutions Manual

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CHAPTER 1

The Role of Analysis in Engineering

END-OF-CHAPTER PROBLEMS

Analysis and Engineering Design

1.1 Essay

1.2 A 1-m long cantilevered beam of rectangular cross section carries a uniform load of $w = 15$ kN/m. The design specification calls for a 5-mm maximum deflection of the end of the beam. The beam is to be constructed of fir ($E = 13$ GPa). By analysis, determine at least five combinations of beam height h and beam width b that meet the specification. Use the equation

$$y_{max} = \frac{wL^4}{8EI}$$

where,

y_{max} = deflection of end of beam (m)
w = uniform loading (N/m)
L = beam length (m)
E = modulus of elasticity of beam (N/m^2)
$I = bh^3/12$ = moment of inertia of beam cross section (m^4)

Note: 1 Pa = 1 N/m^2, 1 kN = 10^3 N and 1 GPa = 10^9 Pa.

What design conclusions can you draw about the influence of beam height and width on the maximum deflection? Is the deflection more sensitive to h or b? If the beam were constructed of a different material, how would the deflection change? See Figure P1.2 for an illustration of the beam.

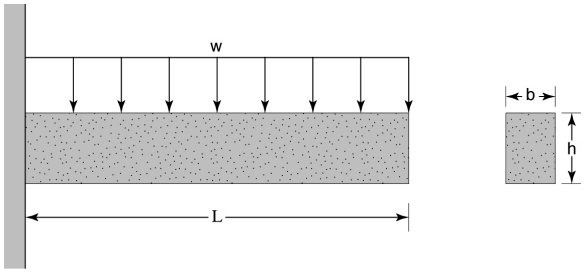


Figure P1.2

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Solution

Given information:

$L = 1\text{m}$ $\quad w = 15 \times 10^3$ N/m $\quad y_{max} = 5$ mm $= 0.005$ m

$E = 13 \times 10^9$ Pa $= 13 \times 10^9$ N/m^2

The deflection of the beam, y_{max}, will be calculated for one combination of h and b, and the rest can be done in the same manner.

By trial and error, we choose $h = 200$ mm and $b = 100$ mm. Thus, we have

$$y_{max} = \frac{wL^4}{8EI} = \frac{12\,wL^4}{8Ebh^3}$$

$$= \frac{12(15 \times 10^3 \text{ N/m})(1 \text{ m})^4}{8(13 \times 10^9 \text{ Pa})(0.1 \text{ m})(0.2 \text{ m})^3}$$

$$= 0.00216 \text{ m} = \underline{2.16 \text{ mm}} < 5 \text{ mm}$$

Other combinations of beam height and width and the corresponding beam deflection are shown below.

y_{max} (mm)	h (mm)	b (mm)
2.16	200	100
2.70	200	80
4.04	175	80
1.11	250	100
3.94	125	225
1.85	175	175
3.42	150	150

An alternative way of doing the calculation is to set y_{max} equal to or below its maximum value, select an arbitrary value of h or b, and then find the other beam dimension.

The beam deflection is directly proportional to beam length, L, and inversely proportional to beam height, h, and beam width, b. Beam deflection is more sensitive to beam height, h, because this dimension is cubed. A beam can be made very stiff, i.e., the deflection can be made very small for a given load, by increasing the beam height. For example, if the beam height is doubled to 400 mm, the maximum deflection is only 0.270 mm.

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If the beam were constructed of a different material, the modulus of elasticity, E, would be different. The beam deflection is inversely proportional to E. Modulus of elasticity is a mechanical property that denotes the stiffness of a material. A higher value of E means a higher stiffness. It is clear that a higher value of E results in a lower beam deflection. For example, if the beam were constructed of structural steel (E = 200 GPa) instead of fir, the beam deflection is only 0.141 mm.

Analysis and Engineering Failure

1.3 Essay

1.4 Essay

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CHAPTER 2

Dimensions and Units

Section 2.2 Practice!

1. For the following dimensional equation, find the base dimensions of the parameter k.

   $ML^2 = k\,LtM^2$

   Solution

   $k = \dfrac{M\,L^2}{L\,t\,M^2} = L\,M^{-1}\,t^{-1}$

2. For the following dimensional equation, find the base dimensions of the parameter g.

   $T^{-1}\,t\,L = g\,L^{-2}$

   Solution

   $g = \dfrac{T^{-1}\,t\,L}{L^{-2}} = L^3\,t\,T^{-1}$

3. For the following dimensional equation, find the base dimensions of the parameter h.

   $It^{-1}\,h = N$

   Solution

   $h = \dfrac{I\,t^{-1}}{N} = N\,I^{-1}\,t$

4. For the following dimensional equation, find the base dimensions of the parameter f.

   $MM^{-3} = a\cos(f\,L)$

   Solution

   The argument of a function must be dimensionless, so the parameter f must have the dimension of reciprocal length. Note also that the left side of the equation is dimensionless.

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Thus,

$f = L^{-1}$

5. For the following dimensional equation, find the base dimension of the parameter p.

$T = T \log(T^{-2}\, t\, p)$

Solution

The argument of a function must be dimensionless, so the parameter p must have the dimensions

$p = T^2 t^{-1}$

Section 2.4 Practice!

1. A structural engineer states that an I-beam in a truss has a design stress of "five million, six hundred thousand pascals". Write this stress using the appropriate SI unit prefix.

Solution

Stress = 5,600,000 Pa = 5.6×10^6 Pa = 5.6 MPa

2. The power cord on an electric string trimmer carries a current of 5.2 A. How many milli-amperes is this? How many microamperes?

Solution

There are 10^3 mA and 10^6 μA in 1 A. Thus,

5.2 A = 5.2×10^3 mA = 5.2×10^6 μA

3. Write the pressure 7.2 GPa in scientific notation.

Solution

7.2 GPa = 7.2×10^9 Pa

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4. Write the voltage 0.000875 V using the appropriate SI unit prefix.

Solution

$0.000875\ \text{V} = 0.875 \times 10^{-3}\ \text{V} = 0.875\ \text{mV} = 875\ \mu\text{V}$

5. In the following list, various quantities are written using SI units incorrectly. Write the quantities using the correct form of SI units.

	Incorrect	Correct
a.	4.5 mw	4.5 mW
b.	8.75 M pa	8.75 MPa
c.	200 Joules/sec	200 J/s
d.	20 W/m^2 K	20 $\text{W/m}^2 \cdot \text{K}$
e.	3 Amps	3 A

Section 2.6 Practice!

1. Essay.

2. Which is larger, a slug or a pound-mass?

Solution

From Appendix B,

$1\ \text{kg} = 2.20462\ \text{lb}_\text{m} = 0.06852\ \text{slug}.$

Dividing by 0.06852, we obtain

$32.17\ \text{lb}_\text{m} = 1\ \text{slug}.$

Thus, a slug is larger than a pound-mass (by a factor of 32.17).

3. Consider a professional linebacker who weighs 310 lb_f. What is his mass in slugs?

Solution

$W = mg$

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$$m = \frac{W}{g} = \frac{310 \text{ lb}_f}{32.2 \text{ ft/s}^2}$$

$$= 9.63 \text{ slug}$$

4. A rock ($\rho = 2300 \text{ kg/m}^3$) is suspended by a single rope. Assuming the rock to be spherical with a radius of 20 cm, what is the tension in the rope?

Solution

If the weight of the rope itself is neglected, the tension in the rope is equivalent to the weight of the rock. The weight of the rock is

$$W = mg$$

where m is the mass of the rock and $g = 9.81 \text{ m/s}^2$.

$$m = \rho V = \rho (4/3) \pi R^3$$

$$= (2300 \text{ kg/m}^3)(4/3)\pi(0.20 \text{ m})^3$$

$$= 77.07 \text{ kg}$$

$$W = mg = (77.07 \text{ kg})(9.81 \text{ m/s}^2)$$

$$= 756 \text{ N}$$

Section 2.7 Practice!

1. A micro switch is an electrical switch that requires only a small force to operate it. If a micro switch is activated by a 0.25-oz force, what is the force in units of N that will activate it?

Solution

$$0.25 \text{ oz} \times \frac{1 \text{ lb}_f}{16 \text{ oz}} \times \frac{1 \text{ N}}{0.22481 \text{ lb}_f} = 0.0695 \text{ N}$$

2. At room temperature, water has a density of about 62.4 lb_m/ft^3. Convert this value to units of slug/in^3 and kg/m^3.

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Solution

$$\frac{62.4\ \text{lb}_m}{\text{ft}^3} \times \frac{1\ \text{slug}}{32.17\ \text{lb}_m} \times \frac{1\ \text{ft}^3}{(12\ \text{in})^3} = 1.12 \times 10^{-3}\ \text{slug/in}^3$$

$$\frac{62.4\ \text{lb}_m}{\text{ft}^3} \times \frac{1\ \text{kg}}{2.20462\ \text{lb}_m} \times \frac{(3.2808\ \text{ft})^3}{(1\ \text{m})^3} = 999.5\ \text{kg/m}^3$$

3. At launch, the Saturn V rocket that carried astronauts to the moon developed five million pounds of thrust. What is the thrust in units of MN?

Solution

$$5 \times 10^6\ \text{lb}_f \times \frac{1\ \text{N}}{0.22481\ \text{lb}_f} = 2.22 \times 10^7\ \text{N} = 22.2\ \text{MN}$$

4. Standard incandescent light bulbs produce more heat than light. Assuming that a typical house has twenty 60-W bulbs that are continuously on, how much heat in units of Btu/h is supplied to the house from light bulbs if 90 percent of the energy produced by the bulbs is in the form of heat?

Solution

$$0.90 \times 20 \times 60\ \text{W} \times \frac{3.4121\ \text{Btu/h}}{1\ \text{W}} = 3685\ \text{Btu/h}$$

5. Certain properties of animal tissue (including human) can be approximated using those of water. Using the density of water at room temperature, $\rho = 62.4\ \text{lb}_m/\text{ft}^3$, calculate the weight of a human male by approximating him as a cylinder with a length and diameter of 6 ft and 10 in, respectively.

Solution

The density of water in units of slug/ft^3 is

$$62.4\ \text{lb}_m/\text{ft}^3 \times \frac{0.001940\ \text{slug/ft}^3}{0.06243\ \text{lb}_m/\text{ft}^3} = 1.9391\ \text{slug/ft}^3$$

The weight of the male is

$$W = mg$$

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$= \rho Vg = \rho\pi R^2 Lg$

$= (1.9391 \text{ slug/ft}^3)\pi(0.4167 \text{ ft})^2(6 \text{ ft})(32.2 \text{ ft/s}^2)$

$= 204 \text{ lb}_f$

6. The standard frequency for electrical power in the U.S. is 60 Hz. For an electrical device that operates on this power, how many times does the current alternate during a year?

Solution

The unit Hz is defined as one cycle per second. Thus,

$$\frac{60 \text{ cycle}}{\text{s}} \times \frac{3600 \text{ s}}{\text{h}} \times \frac{24 \text{ h}}{\text{day}} \times \frac{365 \text{ day}}{\text{year}} = 1.89 \times 10^9 \text{ cycle/year}$$

END-OF-CHAPTER PROBLEMS

Dimensions

2.1 For the following dimensional equations, find the base dimensions of the parameter *k*.

a. $M\,Lt = k\,M\,L^{-1}\,t^{-2}$

Solution

$$k = \frac{M\,L\,t}{M\,L^{-1}\,t^{-2}} = L^2\,t^3$$

b. $M\,L\,t^{-2}\,L^{-1} = k\,Lt^{-3}$

Solution

$$k = \frac{M\,L\,t^{-2}\,L^{-1}}{L\,t^{-3}} = M\,t\,L^{-1}$$

c. $L^3\,t^{-2} = k\,M^3\,T$

Solution

$$k = \frac{L^3\,t^{-2}}{M^3\,T} = L^3\,M^{-3}\,T^{-1}\,t^{-2}$$

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d. $M L^2 t^{-3} = k\, LT$

Solution

$$k = \frac{M L^2 t^{-3}}{LT} = M L T^{-1} t^{-3}$$

e. $n L L^3 k = T^2 M^{-2} L$

Solution

$$k = \frac{T^2 M^{-2} L}{n L L^3} = T^2 M^{-2} n^{-1} L^{-3}$$

f. $M I^2 k = n T M^{-3} L^{-1}$

Solution

$$k = \frac{n T M^{-3} L^{-1}}{M I^2} = n T M^{-4} I^{-2} L^{-1}$$

g. $I L^{-2} t = k^2 M^4 t^2$

Solution

$$k^2 = \frac{I L^{-2} t}{M^4 t^2} = I L^{-2} M^{-4} t^{-1}$$

$$k = I^{1/2} L M^{-2} t^{-1/2}$$

h. $k^3 T^6 M^3 L^{-5} = T^{-3} t^{-6} L$

Solution

$$k^3 = \frac{T^{-3} t^{-6} L}{T^6 M^3 L^{-5}} = L^6 M^{-3} T^{-9} t^{-6}$$

$$k = L^2 M^{-1} T^{-3} t^{-2}$$

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i. $T^{-1/2}\,L^{-1}\,I^2 = k^{-1/2}\,t^4\,T^{-5/2}\,L^{-3}$

Solution

$$k^{-1/2} = \frac{T^{-1/2}\,L^{-1}\,I^2}{t^4\,T^{-5/2}\,L^{-3}} = \frac{1}{k^{1/2}}$$

$$k^{1/2} = \frac{t^4\,T^{-5/2}\,L^{-3}}{T^{-1/2}L^{-1}\,I^2} = I^{-2}\,L^{-2}\,T^{-2}\,t^4$$

$$k = I^{-1}\,L^{-4}\,T^{-4}\,I^8$$

j. $M\,L\,t^{-2} = M\,L\,t^{-2}\sin(k\,L^{-2}\,M^{-1})$

Solution

The argument of the sine function must be dimensionless, so

$$k = L^2\,M$$

k. $T^2\,n = T^2\,n\ln(k\,nT^{-1})$

Solution

The argument of the natural logarithm must be dimensionless, so

$$k = n^{-1}T$$

2.2 Is the following dimensional equation dimensionally consistent? Explain.

$ML = ML\cos(Lt)$

No, this equation is not dimensionally consistent because the argument of the cosine function, Lt, is not dimensionless.

2.3 Is the following dimensional equation dimensionally consistent? Explain.

$t^2\,LT = t\,LT\log(t\,t^{-1})$

No, this equation is not dimensionally consistent because the quantities on the left side of the equation are not the same as those in front of the logarithm on the right side of the equation. The argument of the logarithm is dimensionless, however.

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2.4 Is the following dimensional equation dimensionally consistent? Explain.

$TnT = TnT \exp(MM^{-1})$

Yes, the equation is dimensionally consistent because the argument of the exponential function is dimensionless, and the dimensions on the left side of the equation are the same as those in front of the exponential function.

Units

2.5 In the following list, various quantities are written using SI units incorrectly. Write the quantities using the correct form of SI units.

	Incorrect	Correct
a.	10.6 secs	10.6 s
b.	4.75 amps	4.75 A
c.	120 M hz	120 MHz
d.	2.5 Kw	2.5 kW
e.	0.00846 kg/μs	8460 kg/s
f.	90 W/m^2 K	90 W/m^2·K
g.	525 mGN	525 MN
h.	90 GN.	90 GN
i.	950 Joules	950 J
j.	1.5 m/s/s	1.5 m/s^2
k.	60 W/mK	60 W/m·K
l.	800 N/m/m	800 N/m^2
m.	40 mhz	40 MHz

2.6 The dimension *moment*, sometimes referred to as *torque*, is defined as a force multiplied by a distance and is expressed in SI units of newton-meter (N·m). In addition to moment, what other physical quantities are expressed in SI units of N·m? What is the special name given to this combination of units?

The quantities *work*, *energy* and *heat* are also expressed in SI units of N·m. One newton-meter is equivalent to one joule. Thus, 1 N·m = 1 J.

2.7 Consider a 60-W light bulb. A watt (W) is defined as a joule per second (J/s). Write the quantity 60 W in terms of the units newton (N), meter (m), and second (s).

60 W = 60 J/s = 60 N·m/s

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2.8 A commonly used formula in electrical circuit analysis is $P = IV$, power (W) equals current (A) multiplied by voltage (V). Using Ohm's law, write a formula for power in terms of current, I, and resistance, R.

Ohm's law: $V = IR$

Thus, $P = IV = I(IR) = I^2R$.

2.9 A particle undergoes an average acceleration of 8 m/s^2 as it travels between two points during a time interval of 2 s. Using unit considerations, derive a formula for the average velocity of a particle in terms of average acceleration and time interval. Calculate the average velocity of the particle for the numerical values given.

Solution

It is straightforward to remember that velocity is distance divided by time,

$$v = x/t$$

because we know that the units for velocity are length divided by time, or m/s in this instance. To derive a formula that relates acceleration, velocity and time, we recognize that acceleration differs from velocity by an extra time unit in the denominator, i.e., the SI units for acceleration are m/s^2, whereas the SI units for velocity are m/s. Hence, a formula that relates acceleration, velocity and time is

$$v = at.$$

The average velocity of a particle with an average acceleration of 8 m/s^2 over a time interval of 2 s is

$$v = at = (8 \text{ m/s}^2)(2 \text{ s}) = 16 \text{ m/s}$$

2.10 A crane hoists a large pallet of materials from the ground to the top of a building. In hoisting this load, the crane does 250 kJ of work during a time interval of 5 s. Using unit considerations, derive a formula for power in terms of work and time interval. Calculate the power expended by the crane in lifting the load.

Solution

Power is defined as the rate of doing work. Thus, the units for power in the SI system are J/s, so the formula for power, P, is

$$P = W/t$$

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where W is work and t is time. The power expended by the crane in lifting the load is

$$P = \frac{W}{t} = \frac{250 \text{ kJ}}{5 \text{ s}} = 50 \text{ kJ/s} = 50 \text{ kW}$$

Mass and weight

2.11 A tank measuring 80 cm × 1.20 m × 1.75 m is half filled with water ($\rho = 1000 \text{ kg/m}^3$). Find the mass and the weight of the water in SI units.

Solution

The mass of the water is

$$m = \rho \tfrac{1}{2} V$$

$$= (1000 \text{ kg/m}^3) \tfrac{1}{2} (0.80 \text{ m})(1.20 \text{ m})(1.75 \text{ m})$$

$$= 840 \text{ kg}$$

The weight of the water is

$$W = mg$$

$$= (840 \text{ kg})(9.81 \text{ m/s}^2)$$

$$= 8240 \text{ N}$$

2.12 A large indoor sports arena is cylindrical in shape. The height and diameter of the cylinder are 120 m and 180 m, respectively. Calculate the mass and weight of air contained in the sports arena in SI units if the density of air is $\rho = 1.20 \text{ kg/m}^3$.

Solution

The mass of the air is

$$m = \rho V = \rho \pi R^2 h$$

$$= (1.20 \text{ kg/m}^3)\pi(90 \text{ m})^2(120 \text{ m})$$

$$= 3.66 \times 10^6 \text{ kg}$$

The weight of the air is

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$$W = mg$$

$$= (3.664 \times 10^6 \text{ kg})(9.81 \text{ m/s}^2)$$

$$= 3.595 \times 10^7 \text{ N} = 36.0 \text{ MN}$$

2.13 A 90-kg astronaut biologist searches for microbial life on Mars where the gravitational acceleration is $g = 3.71$ m/s^2. What is the weight of the astronaut in units of N and lb$_f$?

Solution

The weight of the astronaut in units of N is

$$W = mg$$

$$= (90 \text{ kg})(3.71 \text{ m/s}^2)$$

$$= 334 \text{ N}$$

The weight of the astronaut in units of lb$_f$ is

$$W = 334 \text{ N} \times \frac{0.22481 \text{ lb}_f}{\text{N}} = 75.1 \text{ lb}_f$$

2.14 A 90-kg astronaut-biologist places a 4-lb$_m$ rock sample on two types of scales on Mars in order to measure the rock's weight. The first scale is a beam balance which operates by comparing masses. The second scale operates by the compression of a spring. Calculate the weight of the rock sample in (lb$_f$) using (a) the beam balance and (b) the spring scale.

Solution

The mass of the rock in slugs is

$$m = 4 \text{ lb}_m \times \frac{1 \text{ slug}}{32.17 \text{ lb}_m} = 0.1243 \text{ slug}$$

From the previous problem, the gravitational acceleration on Mars is

$$g_M = 3.71 \text{ m/s}^2 \times \frac{3.2808 \text{ ft/s}^2}{1 \text{ m/s}^2} = 12.17 \text{ ft/s}^2$$

(a) Beam balance:

A beam balance measures weight by comparing the weight of an object with the weight of

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a reference weight. The beam balance will indicate that a 4-lb_m rock has a weight that is numerically equivalent to the mass of the rock. Thus, the weight of the rock is the product of its mass and the gravitational acceleration for Earth, $g_E = 32.2$ ft/s^2.

$$W = mg_E = (0.1243 \text{ slug})(32.2 \text{ ft/s}^2) = 4.00 \text{ lb}_f$$

(b) Spring scale:

A spring scale measures weight by the compression of a spring under the load of the object being measured. The spring deflection depends on the local gravitational acceleration. Thus, the weight of the rock as measured by the spring scale on Mars is

$$W = mg_M = (0.1243 \text{ slug})(12.17 \text{ ft/s}^2) = 1.51 \text{ lb}_f$$

2.15 Fifty spherical ball bearings have a diameter of 1.25 cm and a density of $\rho = 8900$ kg/m^3. Find the mass and weight of the ball bearings in SI units.

Solution

The mass of the bearings is

$$m = 50\,\rho V = 50\rho\pi D^3/6$$

$$= (50)(8900 \text{ kg/m}^3)\,\pi\,(0.0125 \text{ m})^3/6$$

$$= 0.4551 \text{ kg}$$

The weight of the plate is

$$W = mg$$

$$= (0.4551 \text{ kg})(9.81 \text{ m/s}^2)$$

$$= 4.465 \text{ N}$$

2.16 A circular tube of stainless steel ($\rho = 7840$ kg/m^3) has an inside radius of 1.85 cm and an outside radius of 2.20 cm. If the tube is 35 cm long, what is the mass and weight of the tube in SI units?

Solution

The mass of the tube, which is a hollow cylinder, is

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$$m = \rho V = \rho\pi(R_o^2 - R_i^2)L$$

$$= (7840 \text{ kg/m}^3)\pi[(0.0220 \text{ m})^2 - (0.0185 \text{ m})^2](0.35 \text{ m})$$

$$= 1.22 \text{ kg}$$

The weight of the tube is

$$W = mg$$

$$= (1.22 \text{ kg})(9.81 \text{ m/s}^2)$$

$$= 12.0 \text{ N}$$

2.17 The density of porcelain is $\rho = 144 \text{ lb}_m/\text{ft}^3$. Approximating a porcelain dinner plate as a flat disk with a diameter and thickness of 9 in and 0.2 in, respectively, find the mass of the plate in units of slug and lb_m. What is the weight of the plate in units of lb_f?

Solution

To work the problem in a consistent set of units, we convert the diameter and thickness to units of ft.

$$D = 9 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.75 \text{ ft}$$

$$t = 0.2 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.0167 \text{ ft}$$

We also convert the density to units of slug/ft^3.

$$\rho = 144 \text{ lb}_m/\text{ft}^3 \times \frac{0.001940 \text{ slug/ft}^3}{0.06243 \text{ lb}_m/\text{ft}^3} = 4.475 \text{ slug/ft}^3$$

The mass of the plate is

$$m = \rho V = \rho(\pi D^2/4)t$$

$$= (4.475 \text{ slug/ft}^3)\pi(0.75 \text{ ft})^2/4(0.0167 \text{ ft})$$

$$= 0.0330 \text{ slug}$$

$$m = 0.0330 \text{ slug} \times \frac{32.17 \text{ lb}_m}{1 \text{ slug}} = 1.06 \text{ lb}_m$$

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The weight of the plate is

$$W = mg = (0.0330 \text{ slug})(32.2 \text{ ft/s}^2) = 1.06 \text{ lb}_f \text{ (numerically equivalent to lb}_m\text{)}$$

2.18 In an effort to reduce the mass of a bulkhead for a spacecraft, an engineer has an array of holes drilled in the bulkhead. The bulkhead is a circular plate with a diameter and thickness of 40 cm and 1.50 cm, respectively. How many 5.0 cm holes must be drilled clear through the bulkhead to reduce its mass by at least 20 percent?

Solution

The total volume of the bulkhead without any holes drilled is

$$V_{\text{total}} = (\pi D^2/4)\, t$$

$$= \pi\, (0.40 \text{ m})^2/4\, (0.0150 \text{ m})$$

$$= 1.885 \times 10^{-3} \text{ m}^3$$

The volume of one hole is

$$V_{\text{hole}} = (\pi D_{\text{hole}}{}^2/4)\, t$$

$$= \pi\, (0.050 \text{ m})^2/4\, (0.0150 \text{ m})$$

$$= 2.945 \times 10^{-5} \text{ m}^3$$

Hence,

$$0.20 V_{\text{total}} = N\, V_{\text{hole}}$$

where N is the required number of holes. So,

$$N = 0.20\, (1.885 \times 10^{-3} \text{ m}^3)/(2.945 \times 10^{-5} \text{ m}^3)$$

$$= 12.8 \text{ holes}$$

In order to reduce the mass of the bulkhead by at least 20 percent, we round the fractional number of holes up to 13, which is our answer. Note that the density of the bulkhead material was not necessary. Furthermore, we could have neglected thickness since the thickness of the bulkhead and holes are the same and divide out in the calculation.

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Unit conversions

2.19 A world-class female hurdler can run 100 m in a time of 12.5 s, an average speed of 8.00 m/s. Convert this speed to units of mi/h.

Solution

$$\frac{8.00\ \text{m}}{\text{s}} \times \frac{0.6214\ \text{mi}}{1000\ \text{m}} \times \frac{3600\ \text{s}}{\text{h}} = 17.9\ \text{mi/h}$$

2.20 A world-class mile runner can run 1 mi in a time of 4 min. What is the runner's average speed in units of mi/h and m/s?

Solution

$$\frac{1\ \text{mi}}{4\ \text{min}} \times \frac{60\ \text{min}}{1\ \text{h}} = 15.0\ \text{mi/h}$$

$$\frac{1\ \text{mi}}{4\ \text{min}} \times \frac{1\ \text{min}}{60\ \text{s}} \times \frac{1000\ \text{m}}{0.6214\ \text{mi}} = 6.71\ \text{m/s}$$

2.21 An office building is heated by a forced-air system that burns fuel oil. If the heat output of the system is 3.75 million Btu/h, what is the heat output in units of MW?

Solution

$$3.75 \times 10^6\ \text{Btu/h} \times \frac{1\ \text{W}}{3.4121\ \text{Btu/h}} \times \frac{1\ \text{MW}}{1.0 \times 10^6\ \text{W}} = 1.10\ \text{MW}$$

2.22 Calculate the temperature at which the Celsius (°C) and Fahrenheit (°F) scales are numerically equal.

Solution

The formula for converting from °C to °F is

$$T(^\circ\text{F}) = 1.8T(^\circ\text{C}) + 32$$

Thus, if $T(^\circ\text{F}) = T(^\circ\text{C}) = T$, the formula becomes

$$T = 1.8T + 32$$

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Solving for T, we obtain

$T = -40°$.

2.23 A large shipping container of ball bearings is suspended by a cable in a manufacturing plant. The combined mass of the container and ball bearings is 3250 lb_m. Find the tension in the cable in units of N.

Solution

The tension in the cable is the combined weight of the container and ball bearings. The total weight is

$$W = mg$$

$$= (3250 \text{ lb}_m) \times \frac{1 \text{ kg}}{2.20462 \text{ lb}_m} \times (9.81 \text{ m/s}^2) = 14.5 \times 10^3 \text{ N} = 14.5 \text{ kN}$$

2.24 A typical human adult loses about 65 Btu/h·ft^2 of heat while engaged in brisk walking. Approximating the human adult body as a cylinder with a height and diameter of 5.8 ft and 10 in, respectively, find the total amount of heat lost in units of J if the brisk walking is maintained for a period of 1 h. Include the two ends of the cylinder in the surface area calculation.

Solution

First, we convert the given quantities from English to SI units. The height and diameter of the cylinder are

$$h = 5.8 \text{ ft} \times \frac{1 \text{ m}}{3.2808 \text{ ft}} = 1.768 \text{ m}$$

$$D = 10 \text{ in} \times \frac{1 \text{ m}}{39.370 \text{ in}} = 0.254 \text{ m} \qquad R = D/2 = 0.127 \text{ m}$$

The heat flux is

$$q = \frac{65 \text{ Btu}}{\text{h}\cdot\text{ft}^2} \times \frac{1055.06 \text{ J}}{1 \text{ Btu}} \times \frac{10.7636 \text{ ft}^2}{1 \text{ m}^2} \times \frac{1 \text{ h}}{3600 \text{ s}} = 205 \text{ J/s}\cdot\text{m}^2 = 205 \text{ W/m}^2$$

The total amount of heat lost is

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where A is total surface area and t is time. Thus, we have

$$Q = q\,(2\pi Rh + 2\pi R^2)t$$

$$= (205\ \text{W/m}^2)[2\pi(0.127\ \text{m})(1.768\ \text{m}) + 2\pi(0.127\ \text{m})^2\ ](3600\ \text{s})$$

$$= 1.12 \times 10^6\ \text{J} = 1.12\ \text{MJ}$$

2.25 A symmetric I-beam of structural steel ($\rho = 7860\ \text{kg/m}^3$) has the cross section shown in Figure P2.25. Calculate the weight per unit length of the I-beam in units of N/m and lb_f/ft.

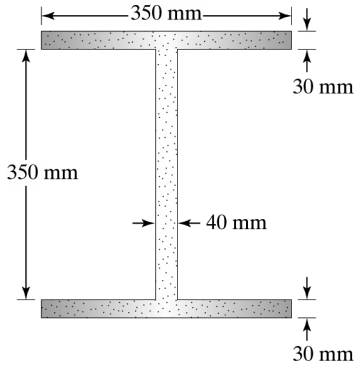


Figure P2.25

Solution

The cross sectional area of the I-beam is the sum of the cross sectional areas of the two flanges and the web. Thus, we have

$$A = 2(0.350\ \text{m})(0.030\ \text{m}) + (0.350\ \text{m})(0.040\ \text{m}) = 0.0350\ \text{m}^2$$

The weight of the I-beam for a 1-m length is

$$W = \rho A g$$

$$= (7860\ \text{kg/m}^3)(0.0350\ \text{m}^2)(9.81\ \text{m/s}^2)$$

$$= 2699\ \text{N/m}$$

Converting this quantity to units of lb_f/ft, we have

$$W = 2699\ \text{N/m} \times 0.22481\ \text{lb}_\text{f}/\text{N} \times 1\ \text{m}/3.2808\ \text{ft}$$

$$= 184.9\ \text{lb}_\text{f}/\text{ft}$$

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2.26 A sewer pipe carries waste away from a commercial building at a mass flow rate of 4.0 kg/s. What is this flow rate in units of kg/day, lb_m/s and slug/h?

Solution

$$\frac{4.0\ kg}{s} \times \frac{24\ h}{day} \times \frac{3600\ s}{h} = 3.46 \times 10^5\ kg/day$$

$$\frac{4.0\ kg}{s} \times \frac{2.20462\ lb_m}{kg} = 8.82\ lb_m/s$$

$$\frac{4.0\ kg}{s} \times \frac{0.06852\ slug}{kg} \times \frac{3600\ s}{h} = 987\ slug/h$$

2.27 The rate at which solar radiation is intercepted by a unit area is called solar heat flux. Just outside the earth's atmosphere, the solar heat flux is approximately 1350 W/m^2. Determine the value of this solar heat flux in units of $Btu/h \cdot ft^2$.

Solution

$$\frac{1350\ W}{m^2} \times \frac{3.4121\ Btu/h}{1W} \times \frac{1\ m^2}{10.7636\ ft^2} = 428\ Btu/h \cdot ft^2$$

2.28 During a typical summer day in the arid southwest regions of the United States, the outdoor air temperature may range from 115°F during the late afternoon to50°F several hours after sundown. What is this temperature range in units of °C, K, and °R?

Solution

$\Delta T(°F) = (115 - 50)°F = 65°F$

$\Delta T(°C) = \Delta T(°F)/1.8 = 65°F/1.8 = 36.1°C$

$\Delta T(K) = \Delta T(°C) = 36.1\ K$

$\Delta T(°R) = \Delta T(°F) = 65°R$

2.29 An old saying is "an ounce of prevention is worth a pound of cure." Restate this maxim in terms of the SI unit newton.

Solution

$$1\ oz \times \frac{1\ lb_f}{16\ oz} \times \frac{1\ N}{0.22481\ lb_f} = 0.2780\ N$$

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$$1\ \text{lb}_\text{f} \times \frac{1\ \text{N}}{0.22481\ \text{lb}_\text{f}} = 4.448\ \text{N}$$

Maxim restated: "0.2780 N of prevention is worth 4.448 N of cure."

2.30 How many seconds are there in the month of March? How many seconds are there in a year consisting of 365 day?

Solution

$$\frac{3600\ \text{s}}{\text{h}} \times \frac{24\ \text{h}}{\text{day}} \times \frac{31\ \text{day}}{\text{month}} = 2.68 \times 10^6\ \text{s}$$

$$\frac{3600\ \text{s}}{\text{h}} \times \frac{24\ \text{h}}{\text{day}} \times \frac{365\ \text{day}}{\text{year}} = 3.15 \times 10^7\ \text{s}$$

2.31 What is your approximate age in seconds?

Solution

$$\text{age (in years)} \times \frac{3600\ \text{s}}{\text{h}} \times \frac{24\ \text{h}}{\text{day}} \times \frac{365\ \text{day}}{\text{y}} = \text{age} \times 3.154 \times 10^7$$

2.32 A highway sign is supported by two posts as shown. The sign is constructed of a high-density press board material ($\rho = 900\ \text{kg/m}^3$), and its thickness is 2 cm. Assuming that each post carries half the weight of the sign, calculate the compressive force in the posts in units of N and lb_f.

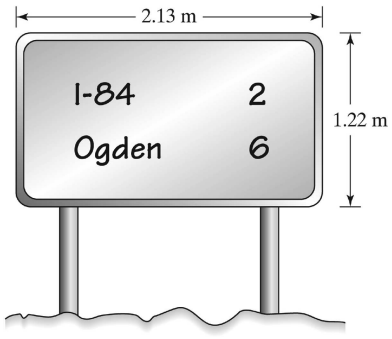


Figure P2.32

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Solution

The weight of the sign is

$$W = mg = V\rho g$$

$$= (2.13\text{ m})(1.22\text{ m})(0.02\text{ m})(900\text{ kg/m}^3)(9.81\text{ m/s}^2)$$

$$= 459\text{ N}$$

Thus, the compressive force in each post is

$$F = W/2 = (459\text{ N})/2 = 229\text{ N}$$

$$F = 229\text{ N} \times \frac{0.22481\text{ lb}_f}{\text{N}} = 51.6\text{ lb}_f$$

2.33 The operating pressure and temperature of the steam in a boiler are 6 MPa and 350°C, respectively. What is the pressure and temperature of the steam in units of psi and °F, respectively?

Solution

$$6\text{ MPa} \times \frac{1000\text{ kPa}}{1\text{ MPa}} \times \frac{0.14504\text{ psi}}{1\text{ kPa}} = 870\text{ psi}$$

$$T(^\circ\text{F}) = 1.8\,T(^\circ\text{C}) + 32$$

$$= (1.8)(350^\circ\text{C}) + 32 = 662^\circ\text{F}$$

2.34 A pressure gauge designed to measure small pressure differences in air ducts has an operating range of 0 to 16 in H_2O. What is this pressure range in units of Pa and psi?

Solution

$$16\text{ in H}_2\text{O} \times \frac{1\text{ kPa}}{4.0146\text{ in H}_2\text{O}} \times \frac{1000\text{ Pa}}{1\text{ kPa}} = 3986\text{ Pa}$$

$$16\text{ in H}_2\text{O} \times \frac{0.14504\text{ psi}}{4.0146\text{ in H}_2\text{O}} = 0.578\text{ psi}$$

2.35 Resistors are electrical devices that retard the flow of current. These devices are rated by the maximum power they are capable of dissipating as heat to the surroundings. How much heat does a 25-W resistor dissipate in units of Btu/h if the resistor operates at maximum capacity?

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Using the formula $P = I^2R$, what is the current flow, I, in the resistor if it has a resistance, R, of 100 Ω?

Solution

$$25 \text{ W} \times \frac{3.4121 \text{ Btu/h}}{1 \text{ W}} = 85.3 \text{ Btu/h}$$

$$I = (P/R)^{1/2}$$

$$= (25 \text{ W}/100 \ \Omega)^{1/2}$$

$$= 0.500 \text{ A}$$

2.36 The fission process within a radioactive material generates heat internally throughout the material's volume. Consider a radioactive material that generates heat at a rate of 80 W/cm^3. Convert this quantity to units of Btu/h · ft^3.

Solution

$$\frac{80 \text{ W}}{\text{cm}^3} \times \frac{3.4121 \text{ Btu/h}}{1 \text{ W}} \times \frac{(100 \text{ cm})^3}{(1 \text{ m})^3} \times \frac{(1 \text{ m})^3}{(3.2808 \text{ ft})^3} = 7.73 \times 10^6 \text{ Btu/h} \cdot \text{ft}^3$$

2.37 A crate of axles for newly-manufactured off-road vehicles holds 60 axles. Each axle has a length and diameter of 4.5 ft and 0.75 in, respectively, and is made of steel ($\rho = 17.2$ slug/ft^3). Find the total mass and weight of the axles in units of slug and lb$_f$, respectively.

Solution

The volume of one axle is

$$V = (\pi D^2/4) L$$

$$= \pi (0.0625 \text{ ft})^2/4(4.5 \text{ ft}) = 0.0138 \text{ ft}^3$$

So, the mass of 60 axles is

$$m = (60)(17.2 \text{ slug/ft}^3)(0.0138 \text{ ft}^3)$$

$$= 14.24 \text{ slug}$$

and the weight of 60 axles is

$$W = mg$$

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$= (14.24 \text{ slug})(32.2 \text{ ft/s}^2)$

$= 458.6 \text{ lb}_f$

2.38 A copper tube carries hot water to a dishwasher at a volume flow rate of 3 gal/min. Convert this flow rate to units of m^3/s and ft^3/h.

Solution

$$\frac{3 \text{ gal}}{\text{min}} \times \frac{1 \text{ m}^3}{264.17 \text{ gal}} \times \frac{1 \text{ min}}{60 \text{ s}} = 1.89 \times 10^{-4} \text{ m}^3/\text{s}$$

$$\frac{3 \text{ gal}}{\text{min}} \times \frac{35.3134 \text{ ft}^3}{264.17 \text{ gal}} \times \frac{60 \text{ min}}{1 \text{ h}} = 24.1 \text{ ft}^3/\text{h}$$

2.39 Thermal conductivity is a property that denotes the ability of a material to conduct heat. A material with a high thermal conductivity readily transports heat whereas a material with a ow thermal conductivity tends to retard heat flow. Fiberglass insulation and silver have thermal conductivities of 0.046 W/m ·°C and 429 W/m ·°C, respectively. Convert these values to units of Btu/h·ft·°F.

Solution

$$\frac{0.046 \text{ W}}{\text{m} \cdot ^\circ\text{C}} \times \frac{3.4121 \text{ Btu/h}}{1 \text{ W}} \times \frac{1 \text{ m}}{3.2808 \text{ ft}} \times \frac{^\circ\text{C}}{1.8^\circ\text{F}} = 0.0266 \text{ Btu/h·ft·°F}$$

$$\frac{429 \text{ W}}{\text{m} \cdot ^\circ\text{C}} \times \frac{3.4121 \text{ Btu/h}}{1 \text{ W}} \times \frac{1 \text{ m}}{3.2808 \text{ ft}} \times \frac{^\circ\text{C}}{1.8^\circ\text{F}} = 248 \text{ Btu/h·ft·°F}$$

2.40 Consider a 40-W LED light bulb with a life of 12,000 h. Find the total amount of energy, expressed in units of kJ, that this light bulb produces during its lifetime.

Solution

$$60 \text{ W} \times \frac{1 \text{ J/s}}{1 \text{ W}} \times \frac{1 \text{ kJ}}{1000 \text{J}} \times \frac{3600 \text{ s}}{1 \text{ h}} \times 12{,}000 \text{ h} = 2.59 \times 10^6 \text{ kJ}$$

2.41 A steam power plant produces 750 MW of power. How much energy does the power plant produce in a year? Express your answer in units of J and Btu.

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Solution

$$750 \text{ MW} \times \frac{1 \times 10^6 \text{ J/s}}{1 \text{ MW}} \times \frac{3600 \text{ s}}{1 \text{ h}} \times \frac{24 \text{ h}}{\text{day}} \times \frac{365 \text{ day}}{1 \text{ y}} = 2.37 \times 10^{16} \text{ J/y}$$

$$2.37 \times 10^{16} \text{ J/y} \times \frac{1 \text{ Btu}}{1055.06 \text{ J}} = 2.25 \times 10^{13} \text{ Btu/y}$$

2.42 It is estimated that about 60 million Americans go on a new diet each year. If each of these people cuts 300 cal from their diets each day, how many 100-W light bulbs could be powered by this energy?

Solution

The 300 cal referred to here are *nutritional* calories, and 1 nutritional calorie equals 1000 calories of energy, i.e., about 4186.8 J. In a one-day period, the number of 100-W light bulbs powered is

$$\frac{300 \times 10^3 \text{ cal}}{\text{day}} \times (60 \times 10^6) \times \frac{4.1868 \text{ J}}{1 \text{ cal}} \times \frac{1 \text{ day}}{24 \text{ h}} \times \frac{1 \text{ h}}{3600 \text{ s}} \times \frac{1 \text{ W}}{1 \text{ J/s}} \times \frac{1}{100 \text{ W}} = 8.72 \times 10^6$$

2.43 The standard acceleration of gravity at the earth's surface is $g = 9.81$ m/s^2. Convert this acceleration to units of ft/h^2 and mi/s^2.

Solution

$$9.81 \frac{\text{m}}{\text{s}^2} \times \frac{3.2808 \text{ ft}}{\text{m}} \times \frac{(3600 \text{ s})^2}{\text{h}^2} = 4.17 \times 10^8 \text{ ft/h}^2$$

$$9.81 \frac{\text{m}}{\text{s}^2} \times \frac{0.6214 \text{ mi}}{1000 \text{ m}} = 6.10 \times 10^{-3} \text{ mi/s}^2$$

2.44 A type of concrete has a specific weight of 9.40 kN/m^3. What is the density of this concrete in units of slug/ft^3?

Solution

The relation between density, ρ, and specific weight, γ, is

$$\gamma = \rho g$$

where g is acceleration of gravity. Thus, the density of the concrete in SI units is

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$$\rho = \gamma/g$$

$$= (9.40 \times 10^3 \text{ N/m}^3)/(9.81 \text{ m/s}^2) = 958.2 \text{ kg/m}^3$$

Converting this value to English units,

$$958.2 \text{ kg/m}^3 \times \frac{0.001940 \text{ slug/ft}^3}{1 \text{ kg/m}^3} = 1.859 \text{ slug/ft}^3$$

2.45 The yield stress for structural steel is approximately 250 MPa. Convert this value to units of psi.

Solution

$$250 \text{ MPa} \times \frac{145.04 \text{ psi}}{\text{MPa}} = 3.63 \times 10^4 \text{ psi}$$

2.46 A 20-gage tungsten wire carries a current of 6.8 A. The electrical resistance of this wire is 106 Ω per kilometer of length. Find the power dissipated from this wire per meter of length in units of W. (Hint: Use the formula $P = I^2R$, where P = power, I = current, R = resistance). How much energy does this wire dissipate in one hour? one year?

Solution

The power dissipated from this wire per meter of length is

$$P = I^2R = (6.8 \text{ A})^2(0.106 \text{ Ω})$$

$$= 4.90 \text{ W}$$

Power is energy per time, so the energy dissipated by the wire in one hour is

$$E = P\,t$$

$$= (4.90 \text{ J/s})\left(1 \text{ h} \times \frac{3600 \text{ s}}{\text{h}}\right) = 1.76 \times 10^4 \text{ J} = 17.6 \text{ kJ}$$

and the energy dissipated by the wire in one year is

$$E = (4.90 \text{ J/s})\left(1 \text{ y} \times \frac{365 \text{ day}}{\text{y}} \times \frac{24 \text{ h}}{\text{day}} \times \frac{3600 \text{ s}}{\text{h}}\right) = 1.55 \times 10^8 \text{ J} = 155 \text{ MJ}$$

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2.47 An open pit copper mine yields 7×10^4 kg of copper per day. From the same ore, the mine also yields 2×10^3 kg of silver and 30 kg of gold per day. In units of lb_m, what is the annual production of these metals from the mine assuming year around operation?

Solution

The annual yield of copper is

$$\text{copper: } 7 \times 10^4 \frac{\text{kg}}{\text{day}} \times \frac{365 \text{ day}}{\text{y}} \times \frac{2.20462 \text{ lb}_m}{\text{kg}} = 5.63 \times 10^7 \text{ lb}_m/\text{y}$$

The annual yield of silver is

$$\text{silver: } 2 \times 10^3 \frac{\text{kg}}{\text{day}} \times \frac{365 \text{ day}}{\text{y}} \times \frac{2.20462 \text{ lb}_m}{\text{kg}} = 1.61 \times 10^6 \text{ lb}_m/\text{y}$$

The annual yield of gold is

$$\text{gold: } 30 \frac{\text{kg}}{\text{day}} \times \frac{365 \text{ day}}{\text{y}} \times \frac{2.20462 \text{ lb}_m}{\text{kg}} = 2.41 \times 10^4 \text{ lb}_m/\text{y}$$

2.48 Linear impulse is a quantity in the subject of dynamics that defines a force acting on a body over a time interval. For simple cases, linear impulse may be expressed as the product of the force and the time interval. Convert the linear impulse of 300 N·s to units of $lb_f \cdot h$.

Solution

$$300 \text{ N·s} \times \frac{0.22481 \text{ lb}_f}{\text{N}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 0.0187 \text{ lb}_f \cdot \text{h}$$

2.49 Overall heat transfer coefficient, U, sometimes called U-value, is a quantity used in the thermal analysis and design of buildings. This quantity is a measure of the heat transmission through a building member such as a wall, roof, or window. Consider a frame wall with a U-value of 0.20 Btu/h·ft^2·°F. Convert this quantity to units of W/m^2·°C. (Hint: The °C unit in this quantity refers to a temperature *change*. A change of one degree Celsius is equivalent to a change of 1.8 degrees Fahrenheit. That is, a degree on the Celsius scale is 1.8 times as large as a degree on the Fahrenheit scale).

Solution

$$\frac{0.20 \text{ Btu}}{\text{h·ft}^2\text{·°F}} \times \frac{1 \text{ W}}{3.4121 \text{ Btu/h}} \times \frac{(3.2808 \text{ ft})^2}{(1 \text{ m})^2} \times \frac{\text{°F}}{1.8\text{°C}} = 0.351 \text{ W/m}^2\text{·°C}$$

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2.50 Kinetic energy is the energy that a system possesses as a result of its motion with respect to a reference frame. The formula for kinetic energy is

$$KE = \tfrac{1}{2}\, m\, v^2$$

where m is mass and v is velocity. Using this formula, show that the SI unit for kinetic energy is the joule (J), which is defined as a newton-meter (N·m).

Solution

The newton is mass times acceleration, so breaking N·m into its base units, we have

$$(\text{kg·m/s}^2)(\text{m}) \rightarrow \text{kg·m}^2/\text{s}^2,$$

mass times velocity squared, which appears in the formula for KE.

2.51 Viscosity may be defined as the property of a fluid that signifies the ease with which the fluid flows under specified conditions. There are two kinds of viscosity, dynamic and kinematic. The units for dynamic viscosity are the pascal-second (Pa·s). (1 Pa = 1 N/m^2). Express dynamic viscosity in terms of SI fundamental units.

Solution

The pascal is defined as a newton per square meter, and the newton is mass times acceleration, so we have

$$\frac{(\text{kg·m/s}^2)}{\text{m}^2}(\text{s}) \rightarrow \text{kg/m·s}$$

2.52 Using Newton's second law, $F = ma$, show that the quantity pressure, which is defined as force divided by area, may be expressed in SI fundamental units as kg/m ·s^2.

Solution

The newton is mass times acceleration, so we have

$$\frac{(\text{kg·m/s}^2)}{\text{m}^2} \rightarrow \text{kg/m·s}^2$$

2.53 A 5 kW resistance heating element runs for two hours to raise the temperature in a water heater to the desired value. In units of kJ, how much energy does this heating element use?

Solution

A kilowatt is a kilojoule per second, so we have

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$$5\ \text{kW} \times \frac{1\ \text{kJ/s}}{\text{kW}} \times 2\ \text{h} \times \frac{3600\ \text{s}}{\text{h}} = 3.60 \times 10^4\ \text{kJ}$$

2.54 For a wind turbine that produces electrical power for a utility company, the output power per unit area swept out by the turbine blades is 2.8 kW/m^2. Convert this power to units of hp/ft^2.

Solution

$$\frac{2.8\ \text{kW}}{\text{m}^2} \times \frac{(1\ \text{m})^2}{(3.2808\ \text{ft})^2} \times \frac{1\ \text{hp}}{0.7457\ \text{kW}} = 0.349\ \text{hp/ft}^2$$

2.55 If an automobile has a fuel economy rating of 28 mi/gal for highway conditions, what is the economy rating in units of kilometer/liter (km/L)?

Solution

$$\frac{28\ \text{mi}}{\text{gal}} \times \frac{1\ \text{km}}{0.6214\ \text{mi}} \times \frac{264.17\ \text{gal}}{1000\ \text{L}} = 11.90\ \text{km/L}$$

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