1.1: PROBLEM DEFINITION

Apply critical thinking to an engineering-relevant issue that is important to you. Create a written document that lists the issue, your reasoning, and your conclusion.

SOLUTION

Student answers will vary.

NOTE TO INSTRUCTOR:
See Appendix A of this Chapter 1 Solution Manual document for active learning in-class activities that may be used as a follow-on to this assignment.

1.2: PROBLEM DEFINITION

Do research on the internet, then create a written document in which you
(a) define what inductive reasoning means and give two concrete examples, and
(b) define what deductive reasoning means and give two concrete examples.
Use the CT process to justify your reasoning and your conclusions.

SOLUTION

Student answers will vary.

NOTES TO INSTRUCTOR:
1. See Appendix A of this Chapter 1 Solution Manual document for active learning in-class activities that may be used as a follow-on to this assignment.
2. One could modify this problem statement. For example, to meet an ABET criterion, such as "demonstration that students have a knowledge of contemporary issues," one could change "an engineering-relevant issue" to "a contemporary engineering-relevant issue".

1.3: PROBLEM DEFINITION

Pick an engineered system that really motivates you. From your favorite engineered system, draft your own definition of engineering. Then, see if your definition of engineering fits the definition of engineering in §1.1. How does this definition compare with yours? What is similar? What is different?

SOLUTION

Student answers will vary.

NOTE TO INSTRUCTOR:
See Appendix A of this Chapter 1 Solution Manual document for active learning in-class activities that may be used as a follow-on to this assignment.

1.4: PROBLEM DEFINITION

Select an engineered design (e.g., hydroelectric power as in a dam, an artificial heart) that involves fluid mechanics and is also highly motivating to you. Write a one-page essay that addresses the following questions: Why is this application motivating to you? How does the system you selected work? What role did engineers play in the design and development of this system?

SOLUTION

Student answers will vary.

NOTE TO INSTRUCTOR:
See Appendix A of this Chapter 1 Solution Manual document for active learning in-class activities that may be used as a follow-on to this assignment.

1.5: PROBLEM DEFINITION

Situation:
(T/F) A fluid is defined as a material that continuously deforms under the action of a normal stress.

Issue:
Is the following statement best characterized as true or as false?
A fluid is defined as a material that continuously deforms under the action of a normal stress.

REASONING:
1. By definition, a fluid is a material that deforms continuously under the action of a "shear stress."
2. The statement states "normal stress."
3. Thus, the given statement is false.
4. Another reason why the given statement is false is that it is easy to find examples in which the given statement is not true. For example, fluid particles in a lake experience normal stresses and there is no flow (i.e. deformation).

CONCLUSION: $\boxed{\text{The best answer is false}}$

NOTE TO INSTRUCTOR:
See Appendix A of this Chapter 1 Solution Manual document for active learning in-class activities that may be used as a follow-on to this assignment.
In particular, the **Clicker or "Vote" Classroom Problem** method would be appropriate.

1.6: PROBLEM DEFINITION

No solution provided; answers will vary. Possible answers could be determined by googling "material properties", which would yield answers such as thermal conductivity, electrical conductivity, tensile strength, etc. The next step would be to discuss how each new material property was different for solids, liquids, and gases.

1.7: PROBLEM DEFINITION

Situation:
Based on molecular mechanisms, explain why aluminum melts at 660 °C whereas ice melts at 0 °C.

SOLUTION

When a solid melts, sufficient energy must be added to overcome the strong intermolecular forces. The intermolecular forces within solid aluminum require more energy to be overcome (to cause melting), than do the intermolecular forces in ice.

1.8: PROBLEM DEFINITION

Situation:
A fluid particle
a. is defined as one molecule
b. is a small chunk of fluid
c. is so small that the continuum assumption does not apply

SOLUTION

The correct answer is b.

1.9: PROBLEM DEFINITION

Situation:

The continuum assumption (select all that apply)

a. applies in a vacuum such as in outer space

b. assumes that fluids are infinitely divisible into smaller and smaller parts

c. is an invalid assumption when the length scale of the problem or design is similar to the spacing of the molecules

d. means that density can idealized as a continuous function of position

e. only applies to gases

SOLUTION

The correct answers are b, c, and d.

1.10: PROBLEM DEFINITION

Note: Student answers will vary. The CT process format (Issue/Reasoning/Conclusion) should be used.

An example answer is provided here.

Issue:
A lift force on an airfoil is caused by air pressure on the bottom of the wing relative to the top of the wing. Therefore, lift force is a pressure force. Use the CT process (see §1.1) to answer whether lift acting on an airfoil is a surface force, or a body force.

Reasoning:
Pressure forces and lift forces have molecules of fluid touching the surface of the wing, and touching is the distinguishing feature of a surface force. Therefore, lift is a surface force, not a body force. A body force is one caused by a field, such as a magnetic, gravitational, or electrical field. *Although gravity influences the pressure distribution in the atmosphere where the plane is flying, the lift (surface) force acts only because the air is pressed against (touching) the airfoil surface.*

Conclusion:
A lift force is a surface force.

1.11: PROBLEM DEFINITION

Situation:

Fill in the blanks. Show your work, using conversion factors found in Table F.1 (EFM11e).

PLAN

Do these unit conversions between different mass units.
Show your work - e.g. canceling and carrying units, using conversion factors found in Table F.1 (EFM11e).

a)

SOLUTION 900 g is _____ slug

$$900\,\mathrm{g} = \left(\frac{900\,\mathrm{g}}{1}\right)\left(\frac{1\,\mathrm{kg}}{1000\,\mathrm{g}}\right)\left(\frac{1\,\mathrm{slug}}{14.59\,\mathrm{kg}}\right)$$

$$\boxed{20\,\mathrm{g} = 0.0617\,\mathrm{slug}}$$

b)

SOLUTION 27 lbm is ______ kg

$$27\text{ lbm} = \left(\frac{27\text{ lbm}}{1}\right)\left(\frac{1\,\mathrm{kg}}{2.205\text{ lbm}}\right)$$

$$\boxed{27\text{ lbm} = 12.2\ \text{ kg}}$$

c)

SOLUTION 100 kg is ______ slugs

$$100\,\mathrm{kg} = \left(\frac{100\,\mathrm{kg}}{1}\right)\left(\frac{1\,\mathrm{slug}}{14.59\,\mathrm{kg}}\right)$$

$$\boxed{100\,\mathrm{kg} = 6.85\ \text{ slug}}$$

d)

SOLUTION 14 lbm is _____ g

$$14\text{ lbm} = \left(\frac{14\text{ lbm}}{1}\right)\left(\frac{453.6\,\mathrm{g}}{1\text{ lbm}}\right)$$

$$\boxed{14\text{ lbm} = 6350\,\mathrm{g}}$$

e)

$\boxed{\text{SOLUTION}}$ 5 slug is _______ lbm

$$5\,\text{slug} = \left(\frac{5\,\text{slug}}{1}\right)\left(\frac{32.17\ \text{lbm}}{1\,\text{slug}}\right)$$

$$\boxed{5\,\text{slug} = 160.8\ \text{lbm}}$$

1.12: PROBLEM DEFINITION

Situation:
What is the approximate mass in units of slugs for
a. A 2-liter bottle of water?
b. A typical adult male?
c. A typical automobile?

a)

PLAN

Mass in slugs for: 2-L bottle of water

SOLUTION

$$\left(\frac{2\text{L}}{}\right)\left(\frac{1000\,\text{kg}}{\text{m}^3}\right)\left(\frac{1\,\text{m}^3}{1000\text{L}}\right)\left(\frac{1\,\text{slug}}{14.59\,\text{kg}}\right)=\boxed{0.137\ \text{slug}}$$

b)

PLAN

Answers will vary, but for 180-lb male:

SOLUTION

On earth 1 lbf weighs 1 lbm
To convert to slugs

$$\left(\frac{180\,\text{lb}}{}\right)\left(\frac{1\,\text{slug}}{32.17\,\text{lb}}\right)=\boxed{5.60\ \text{slug}}$$

c)

PLAN

Answers will vary, but for 3000-lb automobile:

SOLUTION

On earth 1 lbf weighs 1 lbm
To convert to slugs

$$\left(\frac{3000\,\text{lb}}{}\right)\left(\frac{1\,\text{slug}}{32.17\,\text{lb}}\right)=\boxed{93.3\ \text{slug}}$$

1.13: PROBLEM DEFINITION

Answer the following questions related to mass and weight. Show your work, and cancel and carry units.

PLAN

Use $F = ma$, and consider weight and mass units.
In particular, be aware of consistent units and their definitions, such as:

$$1.0 \text{ N} \equiv 1.0\,\text{kg} \times 1.0\,\text{m/s}^2 \qquad \text{and} \qquad 1.0 \text{ lbf} \equiv 1.0\,\text{slug} \times 1.0\,\text{ft/s}^2$$

a)

SOLUTION What is the weight (in N) of a 100-kg body?

$$\begin{aligned} F &= m \times a \quad \text{on earth} \\ W &= (100\,\text{kg})\left(9.81\,\text{m/s}^2\right) \end{aligned}$$

$$\boxed{W = 981\,\text{N}}$$

b)

SOLUTION What is the mass (in lbm) of 20 lbf of water?

$$\begin{aligned} m &= F/a \\ m &= \{\text{force}\} \times \{1/\text{acceleration on earth}\} \times \{\text{identity}\} \\ m &= \left(\frac{20 \text{ lbf}}{1}\right)\left(\frac{\text{s}^2}{32.2 \text{ ft}}\right)\left(\frac{1\,\text{slug} \times 1\,\text{ft/s}^2}{1\,\text{lbf}}\right) \\ m &= 0.621\,\text{slug; next convert to lbm} \\ m &= \left(\frac{0.621\,\text{slug}}{1}\right)\left(\frac{32.2 \text{ lbm}}{1\,\text{slug}}\right) \end{aligned}$$

$$\boxed{m = 20 \text{ lbm}}$$

c)

SOLUTION What is the mass (in slugs) of 20 lbf of water?

$$\begin{aligned} m &= F/a \\ m &= \{\text{force}\} \times \{1/\text{acceleration on earth}\} \times \{\text{identity}\} \\ m &= \left(\frac{20 \text{ lbf}}{1}\right)\left(\frac{\text{s}^2}{32.2 \text{ ft}}\right)\left(\frac{1\,\text{slug} \times 1\,\text{ft/s}^2}{1\,\text{lbf}}\right) \end{aligned}$$

$$\boxed{m = 0.621\,\text{slug};}$$

d) ---

SOLUTION How many N are needed to accelerate 2 kg at 1 m/s^2?

$$\begin{aligned} F &= m \times a \\ F &= (2\,\text{kg})\left(1\,\text{m}/\,\text{s}^2\right) \end{aligned}$$

$$\boxed{F = 2\,\text{N}}$$

e) ---

SOLUTION How many lbf are needed to accelerate 2 lbm at 1 ft/ s^2?

$$\begin{aligned} m &= 2 \;\; \text{lbm} \qquad \text{convert to slugs for consistent units} \\ 2 \;\; \text{lbm} &= \left(\frac{2 \;\; \text{lbm}}{1}\right)\left(\frac{1\,\text{slug}}{32.17 \;\; \text{lbm}}\right) \\ 2 \;\text{lbm} &= 0.06217\,\text{slug} \qquad \text{Now, use } F = m \times a \text{ with the consistent units} \\ F &= m \times a \\ F &= 0.06217\,\text{slug} \times 1\,\text{m}/\,\text{s}^2 \end{aligned}$$

$$\boxed{F = 0.0622\,\text{lbf}}$$

f) ---

SOLUTION How many lbf are needed to accelerate 2 slugs at 1 ft/ s^2?

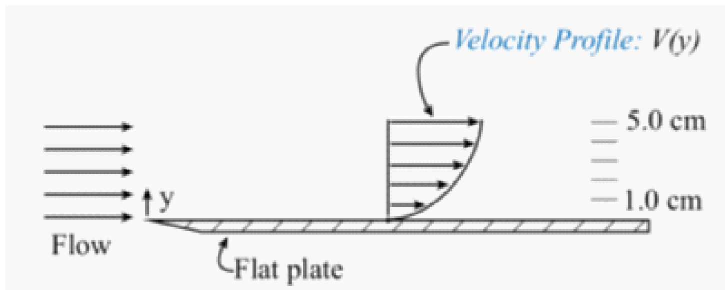
$$\begin{aligned} & \text{Here, units are already consistent} \\ F &= m \times a \\ F &= 2\,\text{slug} \times 1\,\text{m}/\,\text{s}^2 \end{aligned}$$

$$\boxed{F = 2\,\text{lbf}}$$

1.14: PROBLEM DEFINITION

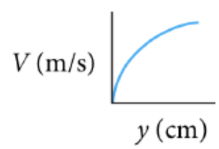
Situation: The sketch shows fluid flowing over a flat surface.

Find: Show how to find the value of the distance y where the derivative dV/dy is maximum.

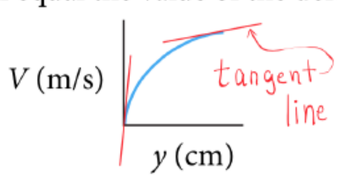


REASONING

1. If you redraw the curve so that the dependent variable (V) is on the vertical axis and the independent variable (y) is on the horizontal axis, the curve looks like this.



2. Now, if you draw a tangent line, the slope of the tangent line will equal the value of the derivative.



3. The y value where dV/dy is maximum is situated where the slope of the tangent line is steepest. This occurs at $y = 0$ cm.

CONCLUSION(S)

$$\boxed{\text{The derivative is maximum where } y = 0\,\text{cm}}$$

1.15: PROBLEM DEFINITION

Situation: An engineer measured the speed of a flowing fluid as a function of the distance y from a wall; the data are shown in the table.

Find: Show how to calculate the maximum value of dV/dy for this data set. Express your answer in SI units.

y (mm)	V (m/s)
0.0	0.00
1.0	1.00
2.0	1.99
3.0	2.97
4.0	3.94

REASONING

Apply the definition of the derivative.

① The def^{n} of the derivative shows that.

$$\frac{dV}{dy} \equiv \lim_{\Delta y \to 0} \frac{\Delta V}{\Delta y} \cong \frac{\Delta V}{\Delta y}$$

② Thus, calc $\Delta V/\Delta y$ as shown below

Example

$\overbrace{2.97 - 1.99 = 0.98}$

y (mm)	V (m/s)	ΔV (m/s)	Δy (m)	$\Delta V/\Delta y$ (s^{-1})
0.0	0.00	1.0	0.001	1000
1.0	1.00	0.99	0.001	990
2.0	1.99	0.98	0.001	980
3.0	2.97	0.97	0.001	970
4.0	3.94			

Example

$\frac{.99}{0.001} = 990$

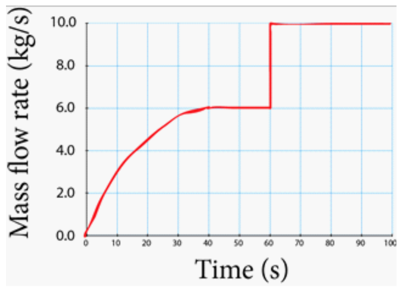
③ The maximum value of dV/dy is $1000\ s^{-1}$

CONCLUSION(S)

$\boxed{\text{The maximum value of } dV/dy \text{ is } 1000\ \text{s}^{-1}}$

1.16: PROBLEM DEFINITION

Situation: The plot shows data taken to measure the rate of water flowing into a tank as a function of time.



Find: Show how to calculate the total amount of water (in kg, accurate to 1 or 2 significant figures) that flowed into the tank during the 100s interval shown.

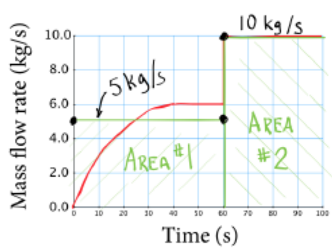
REASONING

1. This problem is an integration problem.

WHAT IS PLOTTED

$$m = \int_{t=0}^{100\,s} \left(\frac{\text{mass}}{\text{time}}\right) dt$$

2. The integration, shown below, gives the total mass.



$$
\begin{aligned}
m &\cong A_1 + A_2 \\
&= \left(\frac{5\ \text{kg}}{\cancel{s}}\right)\left(\frac{60\ \cancel{s}}{1.0}\right) + \left(\frac{10\ \text{kg}}{\cancel{s}}\,\middle|\,\frac{40\ \cancel{s}}{1.0}\right) \\
&= 700\ \text{kg}
\end{aligned}
$$

CONCLUSION(S)

$\boxed{m = 700\,\text{kg (accurate to about 2 SFs where SFs means significant figures)}}$

1.17: PROBLEM DEFINITION

Find:

How are density and specific weight related?

PLAN

Consider their definitions (conceptual and mathematical)

SOLUTION

Density is a [mass]/[unit volume], and specific weight is a [weight]/[unit volume]. Therefore, they are related $\boxed{\text{by the equation } \gamma = \rho g}$, and density differs from specific weight by the factor g, the acceleration of gravity.

1.18: PROBLEM DEFINITION

Situation:

Density is (select all that apply)

a. weight/volume

b. mass/volume

c. volume/mass

d. mass/weight

SOLUTION

Answer is (b) mass/volume.

1.19: PROBLEM DEFINITION

Situation:
Which of these are units of density? (Select all that apply.)
a. kg/m^3
b. mg/cm^3
c. lbm/ft^3
d. $slug/ft^3$

SOLUTION

Correct answers are a, b, c, and d. Each of these is a mass/volume.

1.20: PROBLEM DEFINITION

Situation:

If a gas has $\gamma = 14$ N/m^3 what is its density?
State your answers in SI units and in traditional units.

SOLUTION

Density and specific seight are related according to

$$
\begin{aligned}
\gamma &= \frac{\rho}{g} \\
\text{So } \rho &= \frac{\gamma}{g} \\
\text{For } \gamma &= 14\frac{\mathrm{N}}{\mathrm{m}^3} \\
\text{In SI } \rho &= \left(\frac{14\,\mathrm{N}}{\mathrm{m}^3}\right)\left(\frac{1\,\mathrm{s}^2}{9.81\,\mathrm{m}}\right) \\
\rho &= \boxed{1.43\tfrac{\mathrm{kg}}{\mathrm{m}^3}} \\
&\text{Converting to traditional units} \\
\rho &= \left(\frac{1.427\,\mathrm{kg}}{\mathrm{m}^3}\right)\left(\frac{1\,\mathrm{m}^3}{(3.281^3)\,\mathrm{ft}^3}\right)\left(\frac{1\,\mathrm{slug}}{14.59\,\mathrm{kg}}\right) \\
\rho &= \boxed{2.78\times 10^{-3}\,\tfrac{\mathrm{slug}}{\mathrm{ft}^3}}
\end{aligned}
$$

$\boxed{\text{1.21: PROBLEM DEFINITION}}$

Situation:

Calculate the number of molecules in:
a) One cubic cm of water at room conditions
b) One cubic cm of air at room conditions

a)

$\boxed{\text{PLAN}}$

1. The density of water at room conditions is known (Table A.5, EFM11e), and the volume is given, so:

$$m = \rho \cancel{V}$$

2. From the Internet, water has a molar mass of 18 g/mol, use this to determine the number of moles in this sample.
3. Avogadro's number says that there are 6×10^{23} molecules/mol

$\boxed{\text{SOLUTION}}$

1.

$$m = \rho_{\text{water}} \cancel{V}$$

Assume conditions are atmospheric with $T = 20°C$ and $\rho = 998 \frac{\text{kg}}{\text{m}^3}$

$$\begin{aligned} m_{\text{water}} &= \left(\frac{998\,\text{kg}}{\text{m}^3}\right)\left(\frac{1\,\text{m}^3}{100^3\,\text{cm}^3}\right)\left(1\,\text{cm}^3\right) \\ m_{\text{water}} &= 0.001\,\text{kg} \end{aligned}$$

2. To determine the number of moles:

$$\begin{aligned} \text{number of moles} &= (0.0010\,\text{kg})\left(\frac{1\,\text{mol}}{18\,\text{g}}\right)\left(\frac{1000\,\text{g}}{1\,\text{kg}}\right) \\ \text{number of moles} &= 0.055\,\text{mol} \end{aligned}$$

3. Using Avogadro's number

$$\begin{aligned} & (0.055\,\text{mol})\left(\frac{6 \times 10^{23}\ \text{molecules}}{\text{mol}}\right) \\ \text{number of molecules} &= \boxed{3.3 \times 10^{22}\ \text{molecules}} \end{aligned}$$

b)

$\boxed{\text{PLAN}}$

1. The density of air at room conditions is known (Table A.3, EFM11e), and the volume is given, so:

$$m = \rho \cancel{V}$$

2. From the Internet, dry air has a molar mass of 28.97 g/mol, use this to determine the number of moles in this sample.
3. Avogadro's number says that there are 6×10^{23} molecules/mol

$\boxed{\text{SOLUTION}}$

1.

$$m = \rho_{\text{air}} \cancel{V}$$

Assume conditions are atmospheric with $T = 20°C$ and $\rho = 1.20 \frac{\text{kg}}{\text{m}^3}$

$$\begin{aligned} m_{\text{air}} &= \left(\frac{1.20\,\text{kg}}{\text{m}^3}\right)\left(\frac{1\,\text{m}^3}{100^3\,\text{cm}^3}\right)\left(1\,\text{cm}^3\right) \\ m_{\text{air}} &= 1.2 \times 10^{-6}\,\text{kg} \end{aligned}$$

2. To determine the number of moles:

$$\begin{aligned} \text{number of moles} &= \left(1.2 \times 10^{-6}\,\text{kg}\right)\left(\frac{1\,\text{mol}}{28.97\,\text{g}}\right)\left(\frac{1000\,\text{g}}{1\,\text{kg}}\right) \\ \text{number of moles} &= \boxed{4.14{\times}10^{-5}\,\text{mol}} \end{aligned}$$

3. Using Avogadro's number

$$\begin{aligned} & \left(4.14 \times 10^{-5}\,\text{mol}\right)\left(\frac{6 \times 10^{23}\,\text{molecules}}{\text{mol}}\right) \\ \text{number of molecules} &= 2.5 \times 10^{19}\text{molecules} \end{aligned}$$

$\boxed{\text{REVIEW}}$

There are more moles in one $\text{cm}^3$of water than one cm^3 of dry air. This makes sense, because the molecules in a liquid are held together by weak inter-molecular bonding, and in gases they are not; see Table 1.1 in Section 1.2 (EFM11e).

1.22: PROBLEM DEFINITION

Situation:
Start with the mole form of the Ideal Gas Law, and show the steps to prove that the mass form is correct.

SOLUTION

The molar form is:

$$p\cancel{V} = nR_uT$$

Where n = number of moles of gas, and the Universal Gas Constant = R_u = $8.314\,\mathrm{J/\,mol\cdot\,K}$.
Specific gas constants are given by

$$\begin{aligned} R_{\text{specific}} &= R = \frac{R_u}{\text{molar mass of a gas}} \\ &= \left(\frac{8.314\,\mathrm{J}}{\mathrm{mol\cdot\,K}}\right)\left(\frac{\text{X moles}}{\mathrm{g}}\right) \\ &= 8.314\ \mathrm{X}\ \frac{\mathrm{J}}{\mathrm{g\cdot\,K}} \end{aligned}$$

Indeed, we see that the units for gas constants, R, in table A.2 (EFM11e), are

$$\boxed{\frac{\mathrm{J}}{\mathrm{g\cdot K}}}$$

So

$$\begin{aligned} p\cancel{V} &= \left(R_{\text{specific}}\right)(m)(T) \quad \text{and } \rho = \frac{m}{\cancel{V}} \\ &\boxed{\mathrm{p} = \rho\mathrm{RT}} \end{aligned}$$

Thus the mass form is correct.

1.23: PROBLEM DEFINITION

Situation:
Start with the universal gas constant and show that $\mathrm{R}_{N_2} = 297 \frac{\mathrm{J}}{\mathrm{kg \cdot K}}$.

SOLUTION

Start with universal gas constant:

$$R_u = \frac{8.314\,\mathrm{J}}{\mathrm{mol \cdot K}}$$

The molar mass of nitrogen, N_2, is 28.02 g/mol.

$$\begin{aligned} R_{N_2} &= \frac{R_u}{\text{molar mass}} = \left(\frac{8.314\,\mathrm{J}}{\mathrm{mol \cdot K}}\right)\left(\frac{1\,\mathrm{mol}}{28.02\,\mathrm{g}}\right)\left(\frac{1000\,\mathrm{g}}{1\,\mathrm{kg}}\right) \\ &= \boxed{297 \frac{\mathrm{J}}{\mathrm{kg \cdot K}}} \end{aligned}$$

$\boxed{\text{1.24: PROBLEM DEFINITION}}$

Situation:
Spherical tank of CO_2, does $p_2 = 3p_1$?
Case 1:
$p = 12$ atm
$T = 30°C$
Volume is constant inside the tank
Case 2:
$p = ?$
$T = 90°C$
Volume for case 2 is equivalent to that in case 1

$\boxed{\text{PLAN}}$

1. Volume inside the tank is constant, as is the mass.
   Mass is related to volume by density.
2. Use the Ideal Gas Law to find P_2

$\boxed{\text{SOLUTION}}$

1. Mass in terms of density

$$
\begin{aligned}
m &= \rho \cancel{V} \\
\text{For both case 1 and 2, } \rho_1 &= \frac{m}{\cancel{V}} = \rho_2, \text{ because mass is contained by the tank.}
\end{aligned}
$$

2. Ideal Gas Law for constant volume

$$
\begin{aligned}
\rho &= \frac{p}{RT} \\
\rho_{1,2} &= \frac{p_1}{RT_1} = \frac{p_2}{RT_2} \\
\frac{p_1}{T_1} &= \frac{p_2}{T_2}
\end{aligned}
$$

The Ideal Gas Law applies ONLY if the temperature is absolute, which for this system means Kelvin. In the problem statement, the temperatures were given in Celsius. We need to convert the given temperatures to Kelvin in order to relate them to the pressures. We see therefore that the ratio of temperatures in K is not 1:3. Rather, $30°C = 303.15\,K$, and $90°C = 363.15\,K$.

Therefore, $\frac{T_2}{T_1} = \frac{363.15\,K}{303.15\,K} = \frac{p_2}{p_1} = 1.2$

$\boxed{\Rightarrow \text{No, } p_2 \text{ does not equal } 3p_1\text{. Instead, } p_2 = 1.2\ p_1}$

$\boxed{\text{REVIEW}}$

When working with the IGL, you must alwasy use units for abolute temperature, which means convert T to Rankine (traditional) or Kelvin (SI).

1.25: PROBLEM DEFINITION

Situation:

An engineer needs to know the local density for an experiment with a glider.
$z = 2500\,\text{ft}$.
Local temperature $= 74.3\,^\circ\text{F} = 296.7\,\text{K}$.
Local pressure $= 27.3$ in.-Hg $= 92.45\,\text{kPa}$.

Find:

Calculate density of air using local conditions.
Compare calculated density with the value from Table A.2, and make a recommendation.

Properties:

From Table A.2 (EFM11e), $R_{\text{air}} = 287\ \frac{\text{J}}{\text{kg}\cdot\text{K}} = 287\ \frac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}}$, $\rho = 1.22\,\text{kg/m}^3$.

PLAN

Calculate density by applying the ideal gas law for local conditions.

SOLUTION

Ideal gas law

$$\begin{aligned}\rho &= \frac{p}{RT} \\ &= \frac{92,450\,\text{N/m}^2}{\left(287\frac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}}\right)(296.7\,\text{K})} \\ &= 1.086\ \text{kg/m}^3\end{aligned}$$

$$\boxed{\rho = 1.09\ \text{kg/m}^3\ \text{(local conditions)}}$$

Table value. From Table A.2

$$\boxed{\rho = 1.22\ \text{kg/m}^3\ \text{(table value)}}$$

The density difference (local conditions versus table value) is about 12%. Most of this difference is due to the effect of elevation on atmospheric pressure.

$\boxed{\text{Recommendation–use the local value of density because the effects of elevation are significant}}$.

REVIEW

Note: Use absolute pressure when working with the ideal gas law.

1.26: PROBLEM DEFINITION

Situation:

Carbon dioxide.

Find:

Density and specific weight of CO_2.

Properties:

From Table A.2 (EFM11e), $R_{CO_2} = 189$ J/kg·K.
$p = 114\,\text{kPa}$, $T = 90\,°\text{C}$.

PLAN

1. First, apply the ideal gas law to find density.
2. Then, calculate specific weight using $\gamma = \rho g$.

SOLUTION

1. Ideal gas law

$$\begin{aligned}\rho_{CO_2} &= \frac{P}{RT} \\ &= \frac{114,000\,\text{kPa}}{(189\,\text{J/kg K})\,(90+273)\,\text{K}} \\ &\boxed{\rho_{CO_2} = 1.66\ \text{kg/m}^3}\end{aligned}$$

2. Specific weight

$$\gamma = \rho g$$

Thus

$$\begin{aligned}\gamma_{CO_2} &= \rho_{CO_2} \times g \\ &= 1.66\,\text{kg/m}^3 \times 9.81\,\text{m/s}^2 \\ &\boxed{\gamma_{CO_2} = 16.3\ \text{N/m}^3}\end{aligned}$$

REVIEW

Always use absolute pressure when working with the ideal gas law.

1.27: PROBLEM DEFINITION

Situation:
Methane gas.

Find:
Density (kg/m^3).

Properties:
From Table A.2 (EFM11e), $R_{\text{Methane}} = 518 \ \frac{\text{J}}{\text{kg}\cdot\text{K}}$
$p = 200\,\text{kPa}$, $T = 80\,^{\circ}\text{C}$.

PLAN

1. Apply the ideal gas law to find density.

SOLUTION

1. Ideal gas law

$$\begin{aligned}
\rho_{\text{Methane}} &= \frac{p}{RT} \\
&= \frac{200,000 \frac{\text{N}}{\text{m}^2}}{518 \frac{\text{J}}{\text{kg}\cdot\text{K}} (80 + 273\,\text{K})} \\
& \boxed{\rho_{\text{Methane}} = 1.09 \ \text{kg/m}^3}
\end{aligned}$$

REVIEW

Always use absolute pressure when working with the ideal gas law.

1.28: PROBLEM DEFINITION

Situation:

10 moles of methane gas; molecular weight of methan is 16g/mole.

$p = 5\,\text{bar absolute}$; $5\,\text{bar} = 5 \times 14.50\,\frac{\text{psi}}{\text{bar}} = 72.52\,\frac{\text{lbf}}{\text{in}^2}$ abs; $72.52\,\frac{\text{lbf}}{\text{in}^2}$ abs $= 10,440\,\frac{\text{lbf}}{\text{ft}^2}$ abs

$T = 80^\circ\,\text{F} = 539.7^\circ\,\text{R}$

Find:

Diameter of sphere (ft)

Properties:

$R_{\text{methane}} = 3098\,\frac{\text{ft}\cdot\text{lbf}}{\text{slug}\cdot\,^\circ\text{R}}$

PLAN

1. Find volume to get diameter; relate $\forall_{\text{sphere}}$ to $\forall$ term in the IGL.
2. Moles of methane can be related to mass by molecular weight.
3. Find $\forall$ using form of Ideal Gas Law containing the mass term.
4. Solve for D as per step 1.

SOLUTION

1.

$$\begin{aligned} \forall_{\text{sphere}} &= \frac{4}{3}\pi r^3 = \frac{1}{6}\pi D^3 \\ \Longrightarrow\ D &= \sqrt[3]{\frac{6\forall}{\pi}} \end{aligned}$$

2. Methane, CH_4, has a molecular weight of $\frac{16\,\text{g}}{\text{mol}}$.
Thus, 10 moles of methane weighs 160 g, or 0.160 kg $= 0.011\,\text{slug}$.
3. Ideal Gas Law

$$\begin{aligned} \forall &= \frac{mRT}{p} \\ \forall &= \frac{0.011\,\text{slug} \times 3098\,\frac{\text{ft}\cdot\text{lbf}}{\text{slug}\cdot\,^\circ\text{R}} \times 539.7^\circ R}{10,440\,\frac{\text{lbf}}{\text{ft}^2}} \\ \forall &= 1.756\,\text{ft}^3 \end{aligned}$$

4.Solve for $\forall$ as per step 1.

$$D = \sqrt[3]{\frac{6\forall}{\pi}}$$

$$\boxed{D = 1.50\ \text{ft}}$$

REVIEW

Always convert Temperature to Rankine (traditional) or Kelvin (SI) when working with Ideal Gas Law.

1.29: PROBLEM DEFINITION

Natural gas is stored in a spherical tank.

Find:

Ratio of final mass to initial mass in the tank.

Properties:

$p_{atm} = 100\,\text{kPa}$, $p_1 = 108\,\text{kPa-gage}$.
$p_2 = 204\,\text{kPa-gage}$, $T_1 = T_2 = 12\,^\circ\text{C}$.

PLAN

Use the ideal gas law to develop a formula for the ratio of final mass to initial mass.

SOLUTION

1. Mass in terms of density

$$M = \rho \mathit{V\!\!\!-} \tag{1}$$

2. Ideal gas law

$$\rho = \frac{p}{RT} \tag{2}$$

3. Combine Eqs. (1) and (2)

$$\begin{aligned} M &= \rho \mathit{V\!\!\!-} \\ &= (p/RT)\mathit{V\!\!\!-} \end{aligned}$$

4. Volume and gas temperature are constant, so the cancel when making a ratio comparing case 1 to case 2.

$$\frac{M_2}{M_1} = \frac{p_2}{p_1}$$

and

$$\begin{aligned} \frac{M_2}{M_1} &= \frac{204\ \text{kPa}}{108\ \text{kPa}} \\ &\boxed{\frac{M_2}{M_1} = 1.46} \end{aligned}$$

1.30: PROBLEM DEFINITION

Situation:

Wind and water

$T = 100\,°\mathrm{C}$; $p = 4\,\mathrm{atm} = 405,200\,\mathrm{Pa}$.

Find:

Ratio of density of water to density of air.

Properties:

Air, Table A.2 (EFM11e): $R_{\mathrm{air}} = 287$ J/kg·K.

Water ($100^{o}C$), Table A.5: $\rho_{\mathrm{water}} = 958$ kg/m^3.

PLAN

Apply the ideal gas law to air.

SOLUTION

Ideal gas law

$$\begin{aligned}\rho_{\mathrm{air}} &= \frac{p}{RT} \\ &= \frac{405,200\,\mathrm{Pa}}{(287\,\mathrm{J/\,kg\,K})\,(100+273)\,\mathrm{K}} \\ &= 3.785\ \mathrm{kg/m}^3\end{aligned}$$

For water

$$\rho_{\mathrm{water}} = 958\ \mathrm{kg/m}^3$$

Ratio

$$\frac{\rho_{\mathrm{water}}}{\rho_{\mathrm{air}}} = \frac{958\,\mathrm{kg/\,m^3}}{3.785\,\mathrm{kg/\,m^3}}$$

$$\boxed{\frac{\rho_{\mathrm{water}}}{\rho_{\mathrm{air}}} = 253}$$

REVIEW

Always use absolute pressures when working with the ideal gas law.

1.31: PROBLEM DEFINITION

Situation:

Oxygen fills a tank.

$\forall_{\text{tank}} = 18\,\text{ft}^3$, $W_{\text{tank}} = 150\,\text{lbf}$.

$p = 184$ psia $= 26,496$ psf,

$T = 95\,°\text{F} = (460 + 95)°R = 555°R$

Find:

Weight (tank plus oxygen).

Properties:

From Table A.2 (EFM11e), $R_{\text{O}_2} = 1555$ ft·lbf/(slug $\cdot^{\text{o}}$ R) .

PLAN

1. Apply the ideal gas law to find density of oxygen.
2. Find the weight of the oxygen using specific weight (γ) and add to W_{tank}.

SOLUTION

1. Ideal gas law

$$\begin{aligned}
\rho &= \frac{p}{RT} \\
&= \frac{26,496 \text{ psf}}{(1555\,\text{ft lbf/ slug}^{\text{o}}R)\,(555^{\text{o}}R)} \\
\rho &= 0.0307 \text{ slugs/ft}^3
\end{aligned}$$

2. Specific weight

$$\begin{aligned}
\gamma &= \rho g \\
&= 0.0307\frac{\text{slug}}{\text{ft}^3} \times 32.2\frac{\text{ft}}{\text{s}^2} \\
\gamma &= 0.9885 \text{ lbf/ft}^3
\end{aligned}$$

3. Weight of filled tank

$$\begin{aligned}
W_{\text{oxygen}} &= \gamma \forall \\
W_{\text{oxygen}} &= 0.9885 \text{ lbf/ft}^3 \times 18 \text{ ft}^3 \\
&= 17.79 \text{ lbf} \\
W_{\text{total}} &= W_{\text{oxygen}} + W_{\text{tank}} \\
&= 17.79\,\text{lbf} + 150\,\text{lbf} \\
& \boxed{W_{\text{total}} = 168 \text{ lbf}}
\end{aligned}$$

1.32: PROBLEM DEFINITION

Situation:

Oxygen is released from a tank through a valve.

$\forall = 12\,\mathrm{m}^3$.

Find:

Mass of oxygen that has been released.

Properties:

$\mathrm{R}_{O_2} = 260\frac{\mathrm{J}}{\mathrm{kg\cdot K}}$.

$p_1 = 850\,\mathrm{kPa} = 850,000\,\mathrm{Pa}$ abs; $T_1 = 17\,^\circ\mathrm{C} = 290\,\mathrm{K}$

$p_2 = 650\,\mathrm{kPa} = 650,000\,\mathrm{Pa}$ abs; $T_2 = 17\,^\circ\mathrm{C} = 290\,\mathrm{K}$

PLAN

1. Use ideal gas law, expressed in terms of density and the gas-specific (not universal) gas constant.
2. Find the density for the case before the gas is released; and then mass from density, given the tank volume.
3. Find the density for the case after the gas is released, and the corresponding mass.
4. Calculate the mass difference, which is the mass released.

SOLUTION

1. Ideal gas law

$$\rho = \frac{p}{RT}$$

2. Density and mass for case 1

$$\begin{aligned}
\rho_1 &= \frac{850,000\frac{\mathrm{N}}{\mathrm{m}^2}}{(260\frac{\mathrm{N\cdot m}}{\mathrm{kg\cdot K}})(290\,\mathrm{K})} \\
\rho_1 &= 11.27\frac{\mathrm{kg}}{\mathrm{m}^3}
\end{aligned}$$

$$\begin{aligned}
m_1 &= \rho_1 \forall \\
&= 11.27\frac{\mathrm{kg}}{\mathrm{m}^3} \times 12\,\mathrm{m}^3 \\
m_1 &= 135.3 \text{ kg}
\end{aligned}$$

3. Density and mass for case 2

$$\begin{aligned}
\rho_2 &= \frac{650,000\frac{\mathrm{N}}{\mathrm{m}^2}}{(260\frac{\mathrm{N\cdot m}}{\mathrm{kg\cdot K}})(290\,\mathrm{K})} \\
\rho_2 &= 8.621\frac{\mathrm{kg}}{\mathrm{m}^3}
\end{aligned}$$

$$\begin{aligned}
m_2 &= \rho_1 \cancel{V} \\
&= 8.621 \frac{\text{kg}}{\text{m}^3} \times 12\,\text{m}^3 \\
m_2 &= 103.4 \text{ kg}
\end{aligned}$$

4. Mass released from tank

$$\begin{aligned}
m_1 - m_2 &= 135.3 - 103.4 \\
& \boxed{m_1 - m_2 = 31.9 \text{ kg}}
\end{aligned}$$

1.33: PROBLEM DEFINITION

Situation:

Properties of air.
$p = 730\,\text{kPa}$, $T = 28\,°\text{C}$.

Find:

Specific weight (N/m^3).
Density (kg/m^3).

Properties:

From Table A.2 (EFM11e), $R = 287\ \frac{\text{J}}{\text{kg}\cdot\text{K}}$.

PLAN

First, apply the ideal gas law to find density. Then, calculate specific weight using $\gamma = \rho g$.

SOLUTION

1. Ideal gas law

$$\begin{aligned}\rho_{\text{air}} &= \frac{P}{RT} \\ &= \frac{730,000\,\text{Pa}}{(287\,\text{J/ kg K})\,(28+273)\,\text{K}} \\ & \boxed{\rho_{\text{air}} = 8.45\ \text{kg/m}^3}\end{aligned}$$

2. Specific weight

$$\begin{aligned}\gamma_{\text{air}} &= \rho_{\text{air}} \times g \\ &= 8.45\,\text{kg/ m}^3 \times 9.81\,\text{m/ s}^2 \\ & \boxed{\gamma_{\text{air}} = 82.9\ \ \text{N/ m}^3}\end{aligned}$$

REVIEW

Always use absolute pressure and absolute temperature when working with the ideal gas law.

1.34: PROBLEM DEFINITION

Situation:

Consider a mass of air in the atmosphere.

$\forall = 1.5\,\text{mi}^3$.

Find:

Mass of air using units of slugs and kg.

Properties:

From Table A.2 (EFM11e), $\rho_{\text{air}} = 0.00237$ slugs/ft^3.

Assumptions:

The density of air is the value at sea level for standard conditions.

SOLUTION

Units of slugs

$$M = \rho \forall$$
$$M = 0.00237 \tfrac{\text{slug}}{\text{ft}^3} \times (1.5 \times 5280)^3\,\text{ft}^3$$
$$\boxed{M = 5.23 \times 10^8 \text{ slugs}}$$

Units of kg

$$M = \left(5.23 \times 10^8\,\text{slug}\right) \times \left(14.59 \frac{\text{kg}}{\text{slug}}\right)$$
$$\boxed{M = 7.63 \times 10^9 \text{ kg}}$$

REVIEW

Note the assumption made above stating "The density of air is the value at sea level for standard conditions". This assumption is not safe if extreme accuracy is required because the mass will be somewhat less than we calculated because density decreases with altitude. However our calculation is a good estimate for the purpose of illustrating that we are walking around at the bottom of a heavy ocean of air!

1.35: PROBLEM DEFINITION

Situation:

Design of a CO_2 cartridge to inflate a rubber raft.

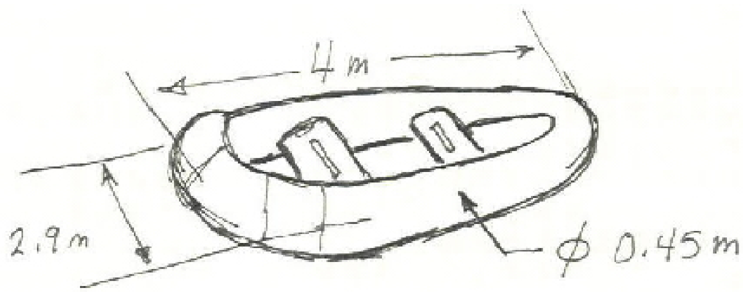
Inflation pressure = 3 psi above p_{atm} = 17.7 psia = 122 kPa abs.

Find:

Estimate the volume of the raft.

Calculate the mass of CO_2 (in grams) to inflate the raft.

Sketch:



Assumptions:

CO_2 in the raft is at 62 °F = 290 K.

Volume of the raft ≈ Volume of a cylinder with $D = 0.45\,\text{m}$ & $L = 16\,\text{m}$ (8 meters for the length of the sides and 8 meters for the lengths of the ends plus center tubes).

Properties:

CO_2, Table A.2 (EFM11e), $R = 189$ J/kg·K.

PLAN

Since mass is related to volume by $m = \rho V$, the steps are:
1. Find volume using the formula for a cylinder.
2. Find density using the ideal gas law (IGL).
3. Calculate mass.

SOLUTION

1. Volume

$$\begin{aligned} V &= \frac{\pi D^2}{4} \times L \\ &= \left(\frac{\pi \times 0.45^2}{4} \times 16 \right) \text{m}^3 \\ &\boxed{V = 2.54 \ \text{m}^3} \end{aligned}$$

2. Ideal gas law

$$\begin{aligned}
\rho &= \frac{p}{RT} \\
&= \frac{122,000\,\mathrm{N/\,m^2}}{(189\,\mathrm{J/\,kg\cdot\ K})\,(290\,\mathrm{K})} \\
&= 2.226\ \mathrm{kg/m^3}
\end{aligned}$$

3. Mass of CO_2

$$\begin{aligned}
m &= \rho\forall \\
&= \left(2.226\ \mathrm{kg/m^3}\right)\left(2.54\,\mathrm{m^3}\right) \\
&\boxed{m = 5660\,\mathrm{g}}
\end{aligned}$$

REVIEW

The final mass (5.66 kg $= 12.5$ lbm) is large. This would require a large and potentially expensive CO_2 tank. Thus, this design idea may be impractical for a product that is driven by cost.

1.36: PROBLEM DEFINITION

Find: List three common units for each variable:
a. Volume flow rate (Q), mass flow rate ($\dot{m}$), and pressure (p).
b. Force, energy, power.
c. Viscosity, surface tension.

PLAN

Use Table F.1 (EFM11e) to find common units

SOLUTION

a. Volume flow rate, mass flow rate, and pressure.

- Volume flow rate, $\mathrm{m^3/s}$, $\mathrm{ft^3/s}$ or cfs, cfm or $\mathrm{ft^3/m}$.
- Mass flow rate, kg/s, lbm/s, slug/s.
- Pressure, Pa, bar, psi or $\mathrm{lbf/in^2}$.

b. Force, energy, power.

- Force, lbf, N, dyne.
- Energy, J, ft·lbf, Btu.
- Power, W, Btu/s, ft·lbf/s.

c. Viscosity.

- Viscosity, Pa·s, kg/(m·s), poise.

Problem 1.37

No solution provided, students are asked to describe the actions for each step of the grid method in their own words.
Note to instructor - you may want to review these to find any excellent perspectives raised by one or more students, to share with the class.

1.38: PROBLEM DEFINITION

Situation:
Which of these is a correct conversion ratio?

SOLUTION

Answers (a) and (b) are correct

1.39: PROBLEM DEFINITION

Situation:
If the local atmospheric pressure is 84 kPa, use the grid method to find the pressure in units of
a. psi
b. psf
c. bar
d. atmospheres
e. feet of water
f. inches of mercury

PLAN

Follow the process given in the text. Look up conversion ratios in Table F.1 (EFM 11e).

a)

SOLUTION

$$\left(\frac{84\,\mathrm{kPa}}{}\right)\left(\frac{1000\,\mathrm{Pa}}{1\,\mathrm{kPa}}\right)\left(\frac{1.450\times10^{-4}\text{ psi}}{\mathrm{Pa}}\right)$$

$$\boxed{84\,\mathrm{kPa}=12.2\text{ psi}}$$

b)

SOLUTION

$$\left(\frac{84\,\mathrm{kPa}}{}\right)\left(\frac{1000\,\mathrm{Pa}}{1\,\mathrm{kPa}}\right)\left(\frac{1.450\times10^{-4}\text{ psi}}{\mathrm{Pa}}\right)\left(\frac{144\,\mathrm{in}^2}{1\,\mathrm{ft}^2}\right)$$

$$\boxed{84\,\mathrm{kPa}=1754\text{ psf}}$$

c)

SOLUTION

$$\left(\frac{84\,\mathrm{kPa}}{}\right)\left(\frac{1000\,\mathrm{Pa}}{1\,\mathrm{kPa}}\right)\left(\frac{1\,\mathrm{bar}}{100000\,\mathrm{Pa}}\right)$$

$$\boxed{84\,\mathrm{kPa}=0.84\,\mathrm{bar}}$$

d)

SOLUTION

$$\left(\frac{84\,\mathrm{kPa}}{}\right)\left(\frac{1000\,\mathrm{Pa}}{1\,\mathrm{kPa}}\right)\left(\frac{1.450\times10^{-4}\ \mathrm{psi}}{\mathrm{Pa}}\right)\left(\frac{1\,\mathrm{atm}}{14.7\ \mathrm{psi}}\right)$$

$$\boxed{84\,\mathrm{kPa} = 0.829\,\mathrm{atm}}$$

e)

SOLUTION

$$\left(\frac{84\,\mathrm{kPa}}{}\right)\left(\frac{1000\,\mathrm{Pa}}{1\,\mathrm{kPa}}\right)\left(\frac{0.004019\ \text{in-H}_20}{\mathrm{Pa}}\right)\left(\frac{1\,\mathrm{ft}}{12\,\mathrm{in}}\right)$$

$$\boxed{84\,\mathrm{kPa} = 28.1\ \text{ft-H}_2\text{O}}$$

f)

SOLUTION

$$\left(\frac{84\,\mathrm{kPa}}{}\right)\left(\frac{1000\,\mathrm{Pa}}{1\,\mathrm{kPa}}\right)\left(\frac{1\ \text{in-Hg}}{3386.39\,\mathrm{Pa}}\right)$$

$$\boxed{84\,\mathrm{kPa} = 24.8\ \text{in-Hg}}$$

1.40: PROBLEM DEFINITION

Apply the grid method.

Situation:

Density of ideal gas is given by:

$$\rho = \frac{p}{RT}$$

$p = 60$ psi, $R = 1716\,\text{ft} \cdot \text{lbf}/\,\text{slug} \cdot\, ^{\circ}\text{R}$.
$T = 180\,^{\circ}\text{F} = 640\ \ ^{\circ}\text{R}$.

Find:

Calculate density (in lbm/ft^3).

PLAN

Use the definition of density.
Follow the process for the grid method given in the text.
Look up conversion formulas in Table F.1 (EFM11e).

SOLUTION

(Note, cancellation of units not shown below, but student should show cancellations on handworked problems.)

$$\begin{aligned}\rho &= \frac{p}{RT} \\ &= \left(\frac{60\,\text{lbf}}{\text{in}^2}\right)\left(\frac{12\,\text{in}}{\text{ft}}\right)^2\left(\frac{\text{slug} \cdot^{\text{o}} \text{R}}{1716\,\text{ft} \cdot \text{lbf}}\right)\left(\frac{1.0}{640\ ^{\text{o}}\text{R}}\right)\left(\frac{32.17\ \text{lbm}}{1.0\,\text{slug}}\right)\end{aligned}$$

$$\boxed{\rho = 0.253\ \ \text{lbm}/\,\text{ft}^3}$$

1.41: PROBLEM DEFINITION

Apply the grid method.

Situation:

Wind is hitting a window of building.

$\Delta p = \frac{\rho V^2}{2}$.

$\rho = 1.2\,\mathrm{kg/m^3}$, $V = 60$ mph.

Find:

a. Express the answer in pascals.

b. Express the answer in pounds force per square inch (psi).

c. Express the answer in inches of water column (in-$H_2 0$).

PLAN

Follow the process for the grid method given in the text. Look up conversion ratios in Table F.1 (EFM11e).

SOLUTION

a)

Pascals.

$$\begin{aligned}\Delta p &= \frac{\rho V^2}{2} \\ &= \frac{1}{2}\left(\frac{1.2\,\mathrm{kg}}{\mathrm{m}^3}\right)\left(\frac{60\text{ mph}}{1.0}\right)^2\left(\frac{1.0\,\mathrm{m/s}}{2.237\text{ mph}}\right)^2\left(\frac{\mathrm{Pa}\cdot\mathrm{m}\cdot\mathrm{s}^2}{\mathrm{kg}}\right)\end{aligned}$$

$$\boxed{\Delta p = 432\,\mathrm{Pa}}$$

b)

Pounds per square inch.

$$\Delta p = 432\,\mathrm{Pa}\left(\frac{1.450\times10^{-4}\text{ psi}}{\mathrm{Pa}}\right)$$

$$\boxed{\Delta p = 0.062\,6\text{ psi}}$$

c)

Inches of water column

$$\Delta p = 432\,\mathrm{Pa}\left(\frac{0.004019\text{ in-H}_2 0}{\mathrm{Pa}}\right)$$

$$\boxed{\Delta p = 1.74\text{ in-H}_2 0}$$

1.42: PROBLEM DEFINITION

Apply the grid method.

Situation:

Force is given by $F = ma$.
a) $m = 10\,\mathrm{kg}$, $a = 10\,\mathrm{m/s^2}$.
b) $m = 10\,\mathrm{lbm}$, $a = 10\,\mathrm{ft/s^2}$.
c) $m = 10\,\mathrm{slug}$, $a = 10\,\mathrm{ft/s^2}$.

Find:

Calculate force.

PLAN

Follow the process for the grid method given in the text. Look up conversion ratios in Table F.1 (EFM11e).

SOLUTION

a)

Force in newtons for $m = 10\,\mathrm{kg}$ and $a = 10\,\mathrm{m/s^2}$.

$$\begin{aligned} F &= ma \\ &= (10\,\mathrm{kg})\left(10\frac{\mathrm{m}}{\mathrm{s}^2}\right)\left(\frac{\mathrm{N}\cdot\mathrm{s}^2}{\mathrm{kg}\cdot\mathrm{m}}\right) \end{aligned}$$

$$\boxed{F = 100\,\mathrm{N}}$$

b)

Force in lbf for $m = 10$ lbm and $a = 10\,\mathrm{ft/s^2}$.

$$\begin{aligned} F &= ma \\ &= (10\ \mathrm{lbm})\left(10\frac{\mathrm{ft}}{\mathrm{s}^2}\right)\left(\frac{\mathrm{lbf}\cdot\mathrm{s}^2}{32.2\ \mathrm{lbm}\cdot\mathrm{ft}}\right) \end{aligned}$$

$$\boxed{F = 3.11\,\mathrm{lbf}}$$

c)

Force in newtons for $m = 10$ slug and acceleration is $a = 10\,\mathrm{ft/s^2}$.

$$\begin{aligned} F &= ma \\ &= (10\,\mathrm{slug})\left(10\frac{\mathrm{ft}}{\mathrm{s}^2}\right)\left(\frac{\mathrm{lbf}\cdot\mathrm{s}^2}{\mathrm{slug}\cdot\mathrm{ft}}\right)\left(\frac{4.448\,\mathrm{N}}{\mathrm{lbf}}\right) \end{aligned}$$

$$\boxed{F = 445\,\mathrm{N}}$$

1.43: PROBLEM DEFINITION

Apply the grid method.

Situation:
A cyclist is traveling along a road.
$P = FV$.
$V = 24\,\text{mi/h}$, $F = 5\,\text{lbf}$.

Find:
a) Find power in watts.
b) Find the energy in food calories to ride for 1 hour.

PLAN

Follow the process for the grid method given in the text. Look up conversion ratios in Table F.1 (EFM11e).

SOLUTION

a)
Power

$$\begin{aligned} P &= FV \\ &= (5\,\text{lbf})\left(\frac{4.448\,\text{N}}{\text{lbf}}\right)(24\text{ mph})\left(\frac{1.0\,\text{m/s}}{2.237\text{ mph}}\right)\left(\frac{\text{W}\cdot\text{s}}{\text{N}\cdot\text{m}}\right) \end{aligned}$$

$$\boxed{P = 239\,\text{W}}$$

b)
Energy

$$\begin{aligned} \Delta E &= P\Delta t \\ &= \left(\frac{239\,\text{J}}{\text{s}}\right)(1\,\text{h})\left(\frac{3600\,\text{s}}{\text{h}}\right)\left(\frac{1.0\text{ calorie (nutritional)}}{4187\,\text{J}}\right) \end{aligned}$$

$$\boxed{\Delta E = 205\text{ calories}}$$

1.44: PROBLEM DEFINITION

Apply the grid method.

Situation:

A pump operates for one year.

$P = 20\,\text{hp}$.

The pump operates for 20 hours/day.

Electricity costs \$0.10/kWh.

Find:

The cost (U.S. dollars) of operating the pump for one year.

PLAN

1. Find energy consumed using $E = Pt$, where P is power and t is time.
2. Find cost using $C = E \times (\$0.1/\text{kWh})$.

SOLUTION

1. Energy Consumed

$$\begin{aligned} E &= Pt \\ &= (20\,\text{hp})\left(\frac{\text{W}}{1.341\times 10^{-3}\,\text{hp}}\right)\left(\frac{20\,\text{h}}{\text{d}}\right)\left(\frac{365\,\text{d}}{\text{year}}\right) \\ &= 1.09\times 10^{8}\,\text{W}\cdot\text{h}\left(\frac{\text{kWh}}{1000\,\text{W}\cdot\text{h}}\right)\text{ per year} \end{aligned}$$

$$\boxed{E = 1.09\times 10^{5}\text{ kWh per year}}$$

2. Cost

$$\begin{aligned} C &= E(\$0.1/\text{kWh}) \\ &= \left(1.09\times 10^{5}\text{ kWh}\right)\left(\frac{\$0.10}{\text{kWh}}\right) \end{aligned}$$

$$\boxed{C = \$10,900}$$

1.45: PROBLEM DEFINITION

Situation:
Of the 3 lists below, which sets of units are consistent? Select all that apply.
a. pounds-mass, pounds-force, feet, and seconds.
b. slugs, pounds-force, feet, and seconds
c. kilograms, newtons, meters, and seconds.

SOLUTION

Answers (a) and (c) are correct.

1.46: PROBLEM DEFINITION

Situation:

List the primary dimensions of each of the following units: kWh, poise, slug, cfm, cSt.

Find:

Primary dimensions for each given unit: kWh, poise, slug, cfm, cSt.

PLAN

1. Find each primary dimension by using Table F.1 (EFM11e).
2. Organize results using a table.

SOLUTION

Unit	**Associated Dimension**	**Associated Primary Dimensions**
kWh	Energy	ML^2/T^2
poise	Viscosity	$M/(L \cdot T)$
slug	Mass	M
cfm	Volume Flow Rate	L^3/T
cSt	Kinematic viscosity	L^2/T

1.47: PROBLEM DEFINITION

Situation: The hydrostatic equation has three common forms:

$$\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2 = \text{ constant}$$

$$p_z = p_1 + \gamma z_1 = p_2 + \gamma z_2 = \text{ constant}$$

$$\Delta p = -\gamma \Delta z$$

Find: For each variable in these equations, list the name, symbol, and primary dimensions of each variable.

PLAN

Look up variables in Table A.6 (EFM11e). Organize results using a table.

SOLUTION

Name	**Symbol**	**Primary dimensions**
pressure	p	M/LT^2
specific weight	γ	M/L^2T^2
elevation	z	L
piezometric pressure	p_z	M/LT^2
change in pressure	Δp	M/LT^2
change in elevation	Δz	L

1.48: PROBLEM DEFINITION

Situation:
In the list below, identify which parameters are dimensions and which paramenters are units: slug, mass, kg, energy/time, meters, horsepower, pressure, and pascals.

SOLUTION

Dimensions: mass, energy/time, pressure
Units: slug, kg, meters, horsepower, pascals

1.49: PROBLEM DEFINITION

Situation:

The hydrostatic equation is

$$\frac{p}{\gamma} + z = C$$

p is pressure, γ is specific weight, z is elevation and C is a constant.

Find:

Prove that the hydrostatic equation is dimensionally homogeneous.

PLAN

Show that each term has the same primary dimensions. Thus, show that the primary dimensions of p/γ equal the primary dimensions of z. Find primary dimensions using Table F.1 (EFM11e).

SOLUTION

1. Primary dimensions of p/γ:

$$\left[\frac{p}{\gamma}\right] = \frac{[p]}{[\gamma]} = \left(\frac{M}{LT^2}\right)\left(\frac{L^2T^2}{M}\right) = L$$

2. Primary dimensions of z :

$$[z] = L$$

3. Dimensional homogeneity. Since the primary dimensions of each term is length, the equation is dimensionally homogeneous. Note that the constant C in the equation will also have the same primary dimension.

1.50: PROBLEM DEFINITION

Situation:
Four terms are given in the problem statement.

Find: Primary dimensions of each term.
a) $\rho V^2/\sigma$ (kinetic pressure).
b) T (torque).
c) P (power).
d) $\rho V^2 L/\sigma$ (Weber number).

SOLUTION

a. Kinetic pressure:

$$\left[\frac{\rho V^2}{2}\right] = [\rho]\,[V]^2 = \left(\frac{M}{L^3}\right)\left(\frac{L}{T}\right)^2 = \frac{M}{L \cdot T^2}$$

b. Torque.

$$[\text{Torque}] = [\text{Force}]\,[\text{Distance}] = \left(\frac{ML}{T^2}\right)(L) = \frac{M \cdot L^2}{T^2}$$

c. Power (from Table F.1, EFM11e).

$$[P] = \frac{M \cdot L^2}{T^3}$$

d. Weber Number:

$$\left[\frac{\rho V^2 L}{\sigma}\right] = \frac{[\rho]\,[V]^2\,[L]}{[\sigma]} = \frac{(M/L^3)\,(L/T)^2\,(L)}{(M/T^2)} = []$$

Thus, this is a dimensionless group

1.51: PROBLEM DEFINITION

Situation:

The power provided by a centrifugal pump is given by:

$$P = \dot{m}gh$$

Find:

Prove that the above equation is dimensionally homogenous.

PLAN

1. Look up primary dimensions of P and $\dot{m}$ using Table F.1 (EFM11e).
2. Show that the primary dimensions of P are the same as the primary dimensions of $\dot{m}gh$.

SOLUTION

1. Primary dimensions:

$$\begin{aligned} [P] &= \frac{M \cdot L^2}{T^3} \\ [\dot{m}] &= \frac{M}{T} \\ [g] &= \frac{L}{T^2} \\ [h] &= L \end{aligned}$$

2. Primary dimensions of $\dot{m}gh$:

$$[\dot{m}gh] = [\dot{m}]\,[g]\,[h] = \left(\frac{M}{T}\right)\left(\frac{L}{T^2}\right)(L) = \frac{M \cdot L^2}{T^3}$$

Since $[\dot{m}gh] = [P]$, $\boxed{\text{The power equation is dimensionally homogenous.}}$

1.52: PROBLEM DEFINITION

Situation:

Two terms are specified.

a. $\int \rho V^2 dA$.

b. $\frac{d}{dt}\int_{\forall} \rho V d\forall$.

Find:

Primary dimensions for each term.

PLAN

1. To find primary dimensions for term a, use the idea that an integral is defined using a sum.
2. To find primary dimensions for term b, use the idea that a derivative is defined using a ratio.

SOLUTION

Term a:

$$\left[\int \rho V^2 dA\right] = [\rho]\left[V^2\right][A] = \left(\frac{M}{L^3}\right)\left(\frac{L}{T}\right)^2 \left(L^2\right) = \boxed{\frac{ML}{T^2}}$$

Term b:

$$\left[\frac{d}{dt}\int_{\forall} \rho V d\forall\right] = \frac{\left[\int \rho V d\forall\right]}{[t]} = \frac{[\rho]\,[V]\,[\forall]}{[t]} = \frac{\left(\frac{M}{L^3}\right)\left(\frac{L}{T}\right)\left(L^3\right)}{T} = \boxed{\frac{ML}{T^2}}$$

1.53: PROBLEM DEFINITION

Note: solutions for this problem will vary, but should include the steps indicated in ***bold****.*

Problem Statement

Apply the WWM and Grid Method to find the acceleraton for a force of 2 N acting on an object of 7 ounces.

Define the situation *(summarize the physics, check for inconsistent units)*

A force acting on a body is causing it to accelerate.

The physics of this situation are described by Newton's 2nd Law of motion, $F = ma$

The units are inconsistent

State the Goal

a <== the acceleration of the object

Generate Ideas and Make a Plan

1. Apply Grid Method
2. Apply Newton's 2nd Law of motion, $F = ma$.
3. Do calculations, and conversions to SI units.
4. Answer should be in m/s^2

Take Action (Execute the Plan)

$$\begin{aligned} F &= ma \\ \frac{2\,\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s}^2} &= \left(\frac{7\text{ oz}}{}\right)\left(\frac{1\,\mathrm{lb}}{16\text{ oz}}\right)\left(\frac{1\,\mathrm{kg}}{2.2\,\mathrm{lb}}\right)\left(\frac{a\,\mathrm{m}}{\mathrm{s}^2}\right) \\ & \boxed{\mathrm{a} = 10.1\ \frac{\mathrm{m}}{\mathrm{s}^2}} \end{aligned}$$

Review the Solution to the Problem

(typical student reflective comment)

This is a straightforword $F = ma$ problem, but in the real world you should always check whether the units are from different systems, and do the appropriate conversions if they are.

Appendix A

Methods for Active Learning in Engineering Classes

Introduction

We have provided some active learning methods for your use because your students will learn more and their levels of engagement will increase.*

Active learning is defined here as having students engage in activities that require critical thinking anc collaboration. The talking/defending components described below will increase student engagement and focus (as compared to being a passive note-taker) in the valuable time when they are in the presence of you, the professor.

I. Team Peer Assessment of Student Work

Rationale. Increase student ownership. Improve students ability to recognize and perform quality technical work.

1. Select a task that is due.
2. Put students in teams of 2, 3, or 4.
3. Have each student in the team present their work to their peers and explain what aspects of the work are done well.
4. Have the team select the work that represents the best of the team and justify why.
5. Have a spokesman from 1 or 2 teams present the work that they found to be the highest quality to the rest of the class.

II. Clicker or "Vote" Classroom Problems

Rationale. Develop skills for self-assessment wherein students perform reasoning, test their reasoning, and correct mis-conceptions.

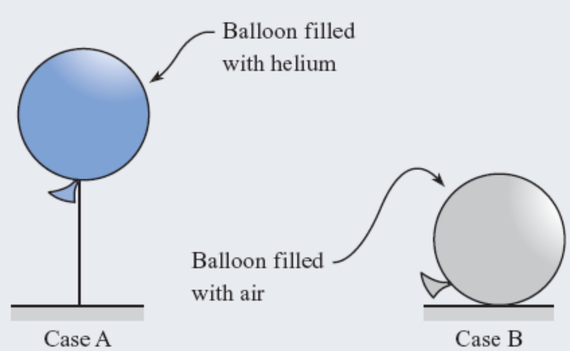
1. Present a conceptual problem on the board with at least 2 multiple choice answers. Consider this example:

Consider a balloon filled with helium (case A) and a balloon filled with air (case B). Which statement is correct?

a. Buoyant force (case A) > Buoyant force (case B)

b. Buoyant force (case A) < Buoyant force (case B)

c. Buoyant force (case A) = Buoyant force (case B)



2. Prepare "distractor" choices that are plausible to novice learners, and can be used to highlight critical elements of a concept (as in the example).

3. Have students discuss the problem in pairs of 2 (optional).
4. Have the class "vote" for what they believe to be the correct choice, either with clickers, or a show of hands.
5. Report exact (clicker) or approximate counts (hands) to the class.
6. Discuss why one answer is correct, and why other answers may seem correct, but are not. If time allows, do this as a class discussion, allowing students to "defend their position". If time is limited, do this yourself.
7. If the 2nd-most-selected choice has part of the correct concept, but not all of it, coach the students to understand how they were "almost right", but how they need to articulate and reject the flawed assumption that allowed them to reach an incorrect conclusion.

III. **Identifying What Students are Doing Well - Engineering Skills**
Rationale. Have student understand and take ownership of skills for doing engineering well.
1. (5 to 10 minutes, before class). Skim your student's homework and identify specific things (e.g. documentation, canceling and carrying units, defining knowns and unknowns, sketch, logical reasoning, etc.) that you think are well done. Make a list of about 8 items.
2. (2 to 4 minutes at the start of next class) Ask your students to select the top two items off the list (e.g., ask them, which 2 item represent the best engineering practices) and to explain why they made these choices. Then direct the students to find a partner, and have them present their findings to a partner and have the student and the partner select their top two as a team. Call on a few students so you can hear what students have come up with.

***NOTE:** You may want to solicit the support of an experienced faculty member who is interested in engineering education if you have not employed active learning before. In your institution, active learning may be novel for engineering students, and you may receive some push-back. Research indicates, however, that active learning, if well-implemented, leads to better performance on exams, and in post-graduate careers.