Problem 1.1

A person who has learned fluid mechanics can do useful things such as tasks a and b on the list that follows. Add 5 more tasks to this list.

a. Modify my car to reduce the drag force (increase fuel economy).
b. Design a water supply system for my city.
c.
d.
e.
f.
g.

Feedback

Feedback. Some examples of possible tasks are:
a. Calculate the wind load on my backpacking tent
b. Design a system to automatically water my plants
c. Design a new type of boat for fun in whitewater
d. Figure out how to make hydroelectric power from a stream near my house
e. Size a pump and water line for a cabin I might build

Problem 1.2

Complete each sentence.

a. *Engineering* involves the knowledge that equips you to ______________________.

b. *Mechanics* involves the knowledge that equips you to ______________________.

c. *Fluid Mechanics* involves the knowledge that equips you to ______________________.

Feedback

Feedback. An example of a possible answer follows.

a. *Engineering*: solve problems that involve technology. This can involve all parts of the technology cycle: invention, design, research, application, sales, and so forth.

b. *Mechanics*: solve engineering problems that involve loads, motion, deformation, and so forth.

c. *Fluid Mechanics*: solve mechanics problems when a fluid is involved.

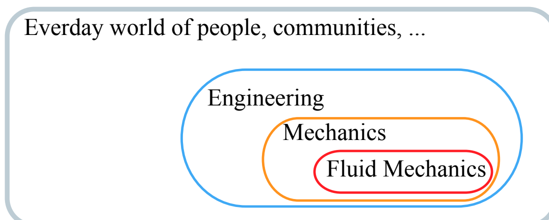
Problem 1.3

Address the following questions:

a. What is engineering?
b. What is mechanics?
c. What is fluid mechanics?
d. How are these topics related?

Feedback

The relationships between engineering, mechanics and fluid mechanics can be shown with a Venn diagram:



In the everyday world, there are professionals called *engineers* who invent, design, and apply technologies such as airplanes, hydroelectric power plants, cars, and computers. Engineers solve problems by applying knowledge from chemistry, circuits, math, thermodynamics, mechanics and so on.

Mechanics is the body of knowledge that describes loads, motion, deformations, and material failure.

One subfield of mechanics is *fluid mechanics* which deals with mechanics problems when the material is a gas or a liquid.

Summary: Fluid mechanics is a subset of mechanics. Mechanics—which is knowledge used by engineers for solving problems that involves loads, motion, deformation, failure, energy, and so on—is a subset of engineering. Engineer itself is used to create, design, improve, and apply technology that benefits people, communities, governments, and so forth.

Problem 1.4

Answer the following questions:

a. What is critical thinking (CT) ?
b. Create a list that describes what you can do if you are skilled at problem solving.
c. According to the standard structure of CT (SSCT), what are the steps for thinking critically?

Feedback

Feedback. One way to answer the questions is like this:

a. Critical thinking is a method for making good decisions.
b. If you are a skilled critical thinker, then you can
   - have a game plan for decision making
   - have confidence in your decisions
   - consistently make good decisions
   - consistently reject bad decisions
   - communicate your decisions effectively
   - analyze a claim made by another person and judge the quality of the claim on a scale that ranges from lousy to excellent
   - decide if a claim is true or not true
   - recognize flawed arguments (fallacies)
c. According to the SSCT, the three steps of CT are:
   i State the issue
   ii State the claim
   iii List premises (aka, facts), definitions, subclaims, and so on that support the claim

Problem 1.5

Compare and contrast liquids and gases by filling out the partially completed template that follows.

First concept	Second concept
gas	liquid

How are the two concepts alike?

1. both phases are compressible
2.
3.
4.

How do the two concepts differ?

smaller; $\sim 1d$	with respect to molecular spacing	larger; $\sim 10d$
	with respect to	
	with respect to	
	with respect to	
	with respect to	

Feedback

First concept	Second concept
gas	liquid

How are the two concepts alike?

1. both phases are compressible
2. both comprised of atoms or molecules
3. both flow due to shear stress
4. common property types: e.g., ρ, γ, and μ

How do the two concepts differ?

gas	with respect to	liquid
smaller; $\sim 1d$	molecular spacing	larger; $\sim 10d$
easily compressible	compressibility	not very compressible
expands to fill	container	takes shape of
if $T\uparrow$, then $\mu\uparrow$	μ versus T	if $T\uparrow$, then $\mu\downarrow$
low	density magnitude	high

1.6: 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: 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.

1.7: 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.

1.8: 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.

Problem 1.9

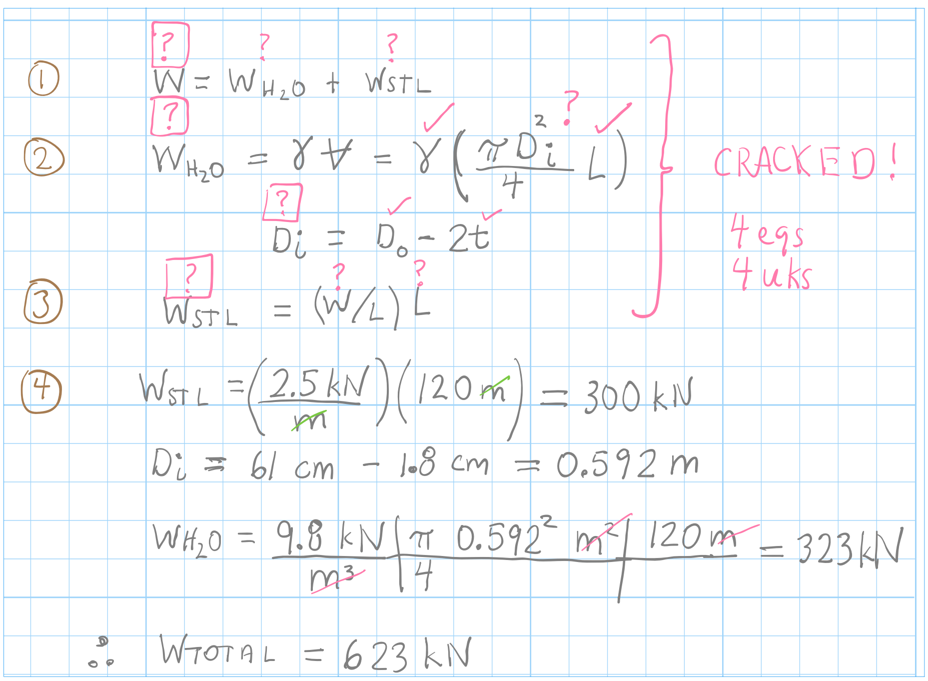
Situation: Water is flowing in a metal pipe. The pipe OD (outside diameter) is 61 cm. The pipe length is 120 m. The pipe wall thickness is 0.9 cm. The water density is 1.0 kg/L. The empty weight of the metal pipe is 2500 N/m.

In kN, what is the total weight (pipe plus water)?
(a) 1100 (b) 530 (c) 950 (d) 620 (e) 740

Feedback

Claim: The best choice is (d).

Reasoning:



The steps are

1. Add the weight of the steel and the water
2. Apply γ = (weight/volume); then, find the inside volume of the pipe using (volume) = (area)(length)
3. Relate the weight of the pipe to its weight/length.
4. Do the calculations

Problem 1.10

The formula in the frame was found on the Internet. Prove that this formula is either valid or invalid. The density of steel is $\approx 7.8\,\text{g/cm}^3$.

Formula: Weight of a steel pipe
The weight per foot of steel pipe is given by WT/FT = (∗OD - ∗WT) x ∗WT x 10.69 where • WT/FT is the weight per foot in units of lbf/ft • ∗OD is the outside diameter of the pipe in inches • ∗WT is the wall thickness in inches This formula is from **http://jdfields.com/pipe-weight-per-foot-calculator/**.

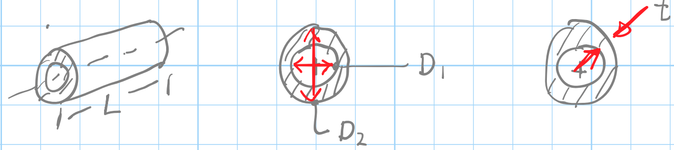
Feedback

Claim: The formula is valid.

Feedback. I derived a formula and then compared my result to the given formula as follows:

(1) $W = mg = \left(\frac{\text{mass}}{\text{volume}}\right)(\text{volume})\,g$ (mass/volume → ρ)

(2)



$$\text{Volume} = \left(\frac{\pi D_2^2}{4} - \frac{\pi D_1^2}{4}\right)L$$

(3) $\therefore\ W/L = \rho g \frac{\pi}{4}(D_2^2 - D_1^2)$

(4) $D_1 = D_2 - 2t$

$\therefore\ D_1^2 = D_2^2 - 4tD_2 + 4t^2$

(5) $\therefore\ \frac{W}{L} = \rho g\left(\frac{\pi}{4}\right)(4tD_2 - 4t^2) = \rho g t \pi (D_2 - t)$

(6) $\rho_{STL} = \rho = (7.8)(1.94\ \text{slug/ft}^3) = 15.132\ \text{slug/ft}^3$

(7) $$\frac{W}{L} = \frac{15.1\ \text{slug}}{\text{ft}^3}\,\Big|\,\frac{32.2\ \text{ft}}{\text{s}^2}\,\Big|\,\pi\,\Big|\,t(D_2 - t)\ \text{in}^2\,\Big|\,\frac{\text{ft}^2}{144\ \text{in}^2}\,\Big|\,\frac{\text{lbf}\cdot\text{s}^2}{\text{slug}\cdot\text{ft}}$$

$$= 10.61\ t(D-t)\ \text{lbf/ft}$$

since $10.61 \approx 10.69$ (8/1000 diff)
the given eqn is CORRECT

The steps are:

1. Apply the weight equation
2. Find the volume of the steel pipe
3. Combine Eqs. (1) and (2)
4. Find D_1 in terms of D_2 and t
5. Combine Eqs (3) and (4)
6. Convert density to consistent units
7. Substitute the appropriate units

Problem 1.11

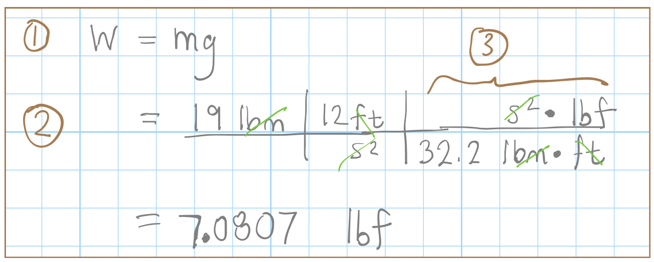
What is the weight in pounds-force of an object with a mass of 19 lbm on a planet where $g = 12\,\text{ft/s}^2$?

(a) 10.2 (b) 19.0 (c) 7.1 (d) 37.0 (e) 3.2

Feedback

Claim: The best choice is (c)

Reasoning:



The steps are:

1. Apply the weight equation
2. Carry and cancel units
3. Apply the definition of the pound force

$$(1.0\,\text{lbf}) \equiv (1.0\,\text{lbm})(32.2\,\text{ft/s}^2)$$

Problem 1.12

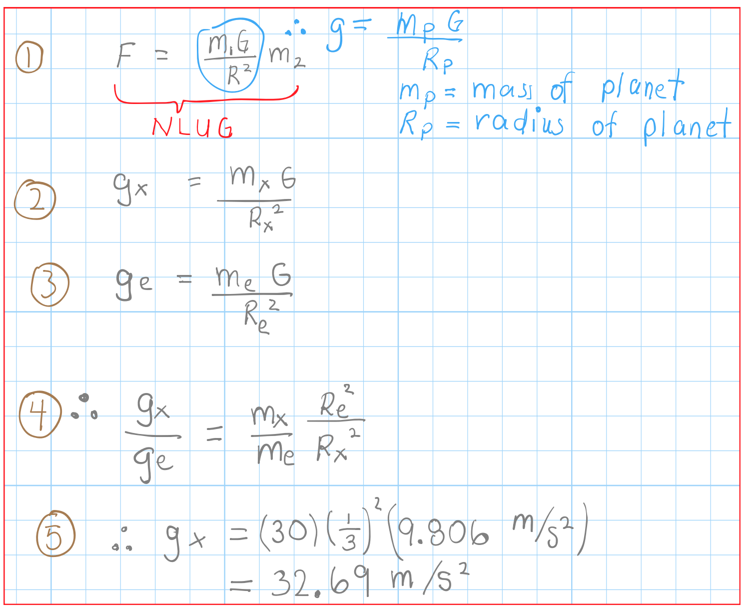
Planet X has a diameter that is 3 times the diameter of Earth and a mass that is 30 times the mass of the Earth. In SI units, what is the gravitational acceleration on planet X?

(a) 32.7 (b) 98.1 (c) 9.81 (d) 0.98 (e) 15.9

Feedback

Claim: The best choice is (a).

Reasoning:



The steps are:

1. From NLUG (Newton's law of universal gravitation), derive the formula for g
2. Apply the formula for g to planet X
3. Apply the formula for g to planet earth
4. Combine Eqs. (2) and (3)
5. Solve for g on planet X

1.13: 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.

1.14: PROBLEM DEFINITION

Situation:

Fill in the blanks. Show your work, using conversion factors found in Table F.1 (EFM12e).

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 (EFM12e).

a)

SOLUTION 900 g is ______ slug

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

$$\boxed{900\,\mathrm{g} = 0.0617\,\mathrm{slug}}$$

b)

SOLUTION 27 lbm is ______ kg

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

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

c)

SOLUTION 100 kg is ______ slugs

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

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

d)

SOLUTION 14 lbm is ______ g

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

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

e)

SOLUTION 5 slug is ________ lbm

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

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

1.15: 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

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

1.16: 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?

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

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

e)

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

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

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

f)

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

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

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

Problem 1.17

A volume V_3 can be calculated using the formula $V_3 = V_2 - V_1$. The parameters are $V_2 = 2.7\,\text{dL}$ and $V_1 = 9.4\,\text{cL}$, where dL and cL are the abbreviations for deciliters and centiliters respectively.

The volume V_3 in units of mL (milliliters) is:
(a) 192 (b) 41 (c) 264 (d) 176 (e) 9

Feedback

Claim: The best choice is (d)

Reasoning:

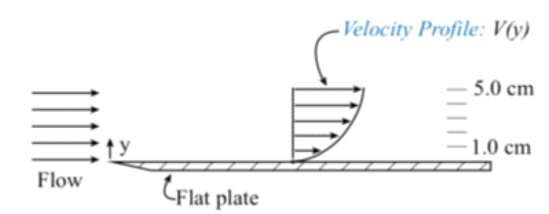
1. A deciliter is equal to one tenth of a liter
2. A centiliter is equal to one hundredth of a liter
3. A milliliter is equal to one thousandth of a liter
4. Thus

$$\begin{aligned} V_3 &= (2.7 \times 10^{-1}\,\text{L}) - (9.4 \times 10^{-2}\,\text{L}) \\ &= 0.176\,\text{L} = 176\,\text{mL} \end{aligned}$$

1.18: PROBLEM DEFINITION

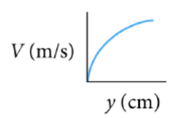
Situation: The sketch shows fluid flowing over a flat surface.

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

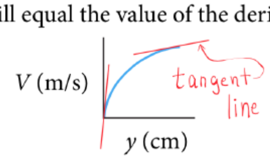


REASONING

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)

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

1.19: 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

① The defn 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: $2.97 - 1.99 = 0.98$

y (mm)	V (m/s)	ΔV (m/s)	Δy (m)	ΔV/Δy (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: $\frac{.99}{0.001} = 990$

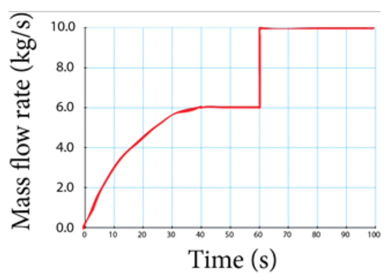
③ The maximum value of dV/dy is $1000\ s^{-1}$

CONCLUSION(S)

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

1.20: 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.

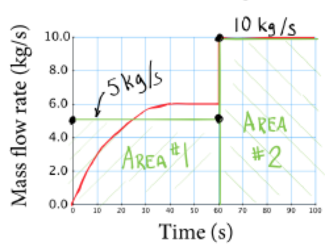
REASONING

1. This problem is an integration problem.

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

WHAT IS PLOTTED

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



$$m \cong A_1 + A_2$$

$$= \left(\frac{5\text{ kg}}{s}\right)\left(\frac{60\text{ s}}{1.0}\right) + \left(\frac{10\text{ kg}}{s}\middle|\frac{40\text{ s}}{1.0}\right)$$

$$= 700\text{ kg}$$

CONCLUSION(S)

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

1.21: 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 by the equation $\gamma = \rho g$, and density differs from specific weight by the factor g, the acceleration of gravity.

1.22: 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

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

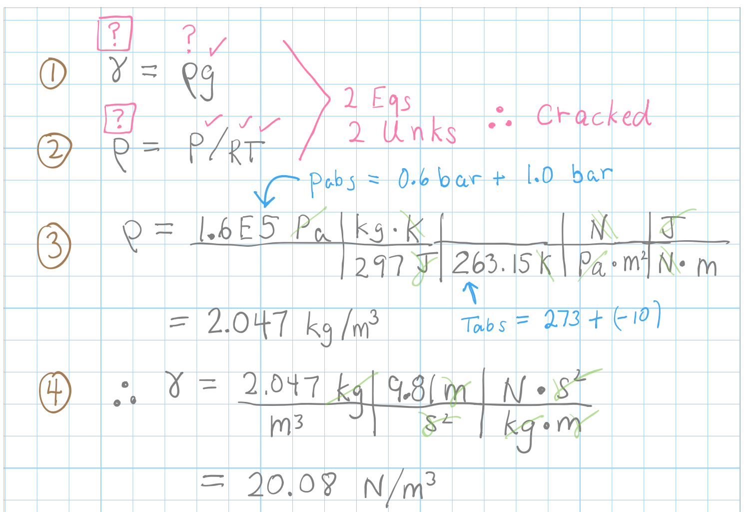
Problem 1.23

What is the specific weight of nitrogen in units of newtons per cubic meter at a temperature of $-10\,^{\circ}\mathrm{C}$ and a pressure of 0.6 bar gage?

(a) 20 (b) 31 (c) 36 (d) 24 (e) 39

Feedback

The best answer is (a). The reasoning follows.



The steps are:

1. Apply the definition of specific weight
2. Apply the IGL
3. Calculate density
4. Calculate specific weight

Problem 1.24

From memory, give the density of water at room conditions.

a. ______ kg/L
b. ______ g/L
c. ______ g/mL
d. ______ kg/(1000 L)
e. ______ kg/m^3
f. ______ $slug/ft^3$
g. ______ lbm/ft^3
h. ______ lbm/(US gallon)
i. ______ lbm/(US quart)

Feedback

Feedback. It is useful to know typical density values of liquid water. These values can be rounded. For example, it is good enough to remember that the density of water is about 8 lbm/gallon.

Density of liquid water is $\rho =$

a. 1.0 kg/L
b. 1000 g/L
c. 1.0 g/mL = 1.0 g/cm^3
d. 1000 kg/(1000 L)
e. 1000 kg/m^3
f. 1.94 $slug/ft^3$
g. 62.4 lbm/ft^3
h. $\approx$ 8 lbm/(US gallon)
i. $\approx$ 2 lbm/(US quart)

Problem 1.25

From memory, give the specific weight of water at room conditions.

a. ____________ N/m^3
b. ____________ N/L
c. ____________ kN/m^3
d. ____________ lbf/ft^3
e. ____________ lbf/(US gallon)
f. ____________ lbf/(US quart)

Feedback

Feedback. It is useful to know typical values of γ for water. Some tips:

1. $\gamma = \rho g$. Thus, $(1.0\,\text{kg/L})(9.81\,\text{m/s}^2) \approx 9.8\,\text{N/L}$
2. Since a mass of 8.0 lbm on earth will have a weight of 8.0 lbf, $\rho \approx 8\,\text{lbm/(US gallon)}$ and $\gamma \approx 8\,\text{lbf/(US gallon)}$
3. Values can be rounded. For example, it is good enough to remember that $\gamma \approx 8$ lbf/gallon

Specific weight of liquid water is $\gamma =$

a. 9810 N/m^3
b. 9.81 N/L
c. 9.81 kN/m^3
d. 62.4 lbf/ft^3
e. $\approx$ 8 lbf/(US gallon)
f. $\approx$ 2 lbf/(US quart)

1.26: 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)

PLAN

1. The density of water at room conditions is known (Table A.5, EFM12e), and the volume is given, so:

$$m = \rho \llap{-}V$$

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

SOLUTION

1.

$$m = \rho_{\text{water}} \llap{-}V$$

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

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

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)

PLAN

1. The density of air at room conditions is known (Table A.3, EFM12e), and the volume is given, so:

$$m = \rho V\!\!\!/$$

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

SOLUTION

1.

$$m = \rho_{\text{air}} V\!\!\!/$$

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:

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

3. Using Avogadro's number

$$(4.14 \times 10^{-5}\,\text{mol})\left(\frac{6 \times 10^{23}\,\text{molecules}}{\text{mol}}\right)$$

$$\text{number of molecules} = \boxed{2.5 \times 10^{19}\,\text{molecules}}$$

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 (EFM12e).

1.27: 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:

$$p\forall = nR_uT$$

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

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

Indeed, we see that the units for gas constants, R, in table A.2 (EFM12e), are

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

So

$$p\forall = (R_{\text{specific}})\,(m)\,(T) \quad \text{and } \rho = \frac{m}{\forall}$$

$$\boxed{\text{p} = \rho\text{RT}}$$

Thus the mass form is correct.

1.28: PROBLEM DEFINITION

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

SOLUTION

Start with universal gas constant:

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

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

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

1.29: 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 (EFM12e), $R = 287\ \frac{\text{J}}{\text{kg}\cdot\text{K}}$.

PLAN

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

SOLUTION

1. Ideal gas law

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

$$\boxed{\rho_{\text{air}} = 8.45\ \text{kg/m}^3}$$

2. Specific weight

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

$$\boxed{\gamma_{\text{air}} = 82.9\ \text{N/ m}^3}$$

REVIEW

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

Problem 1.30

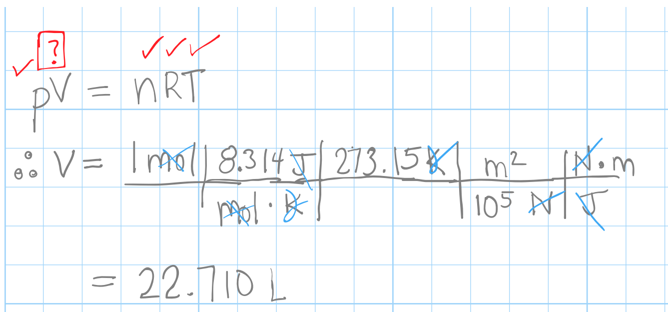
The volume in liters of 1.0 mol of air at STP, which is 0 °C and 1 bar absolute, is

(a) 8 (b) 69 (c) 43 (d) 23 (e) 38

Feedback

Claim: The best choice is (d)

Reasoning:



Problem 1.31

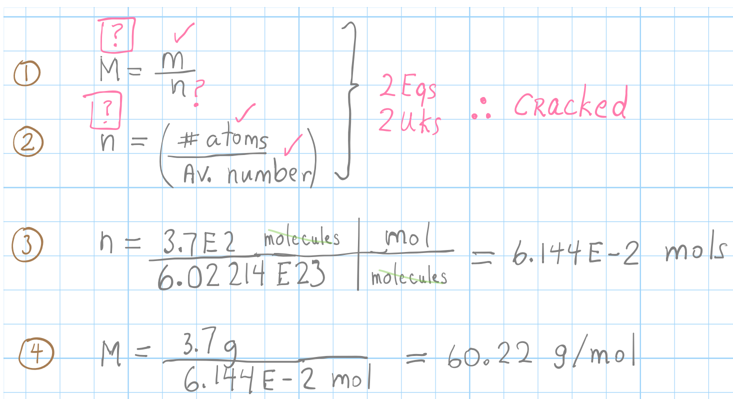
If 3.7 grams of a gas contains 3.7×10^{22} molecules, what is the molar mass of this gas in units of g/mol?

(a) 37 (b) 74 (c) 60 (d) 44 (e) 16

Feedback

Claim: The best choice is (d)

Reasoning:



The steps are:

1. Apply the definition of molar mass
2. Apply the definition of the mole
3. Calculate the number of moles
4. Calculate the molar mass

Problem 1.32

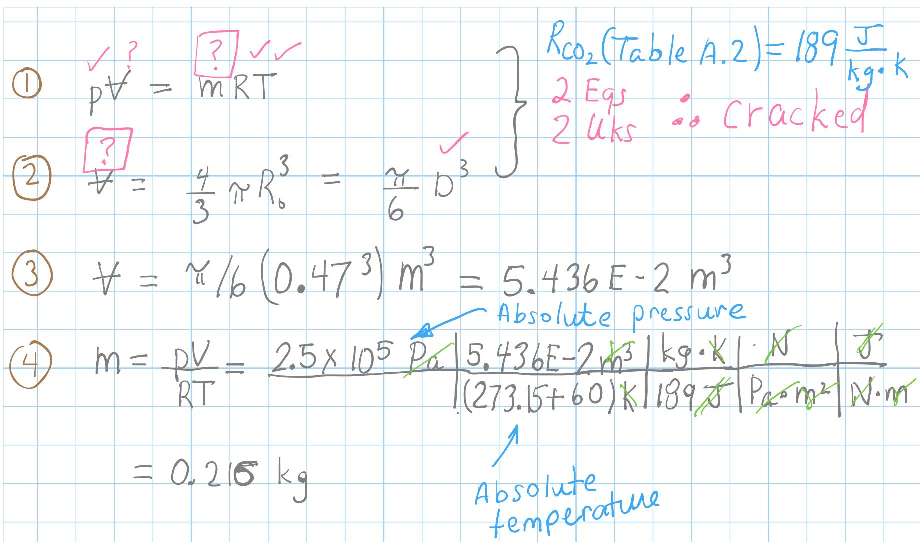
How many grams of carbon dioxide are contained in a 47 cm diameter sphere when the gage pressure is 1.5 bar and the temperature is 60 °C?

(a) 380 (b) 120 (c) 24 (d) 220 (e) 91

Feedback

Claim: The best answer is (d)

Reasoning:



Problem 1.33

The number of mol in 3/8 lbm · mol is

(a) 170 (b) 0.38 (c) 22.4 (d) 2.43 (e) 5.98

Feedback

Claim: The best answer is (a).

Reasoning:

(1) $$(1.0\ \text{lbm}\cdot\text{mol}) = (453.592)(1.0\ \text{mol})$$

(2) $$1.0 \cong \frac{454\ \text{mol}}{\text{lbm}\cdot\text{mol}}$$

(3) $$(3/8\ \text{lbm}\cdot\text{mol})\left(\frac{454\ \text{mol}}{\text{lbm}\cdot\text{mol}}\right) = 170\ \text{mol}$$

The steps are:

1. Apply the definition of the lbm · mol
2. Apply Eq. (1) to build a conversion ratio
3. Do the unit conversion

Problem 1.34

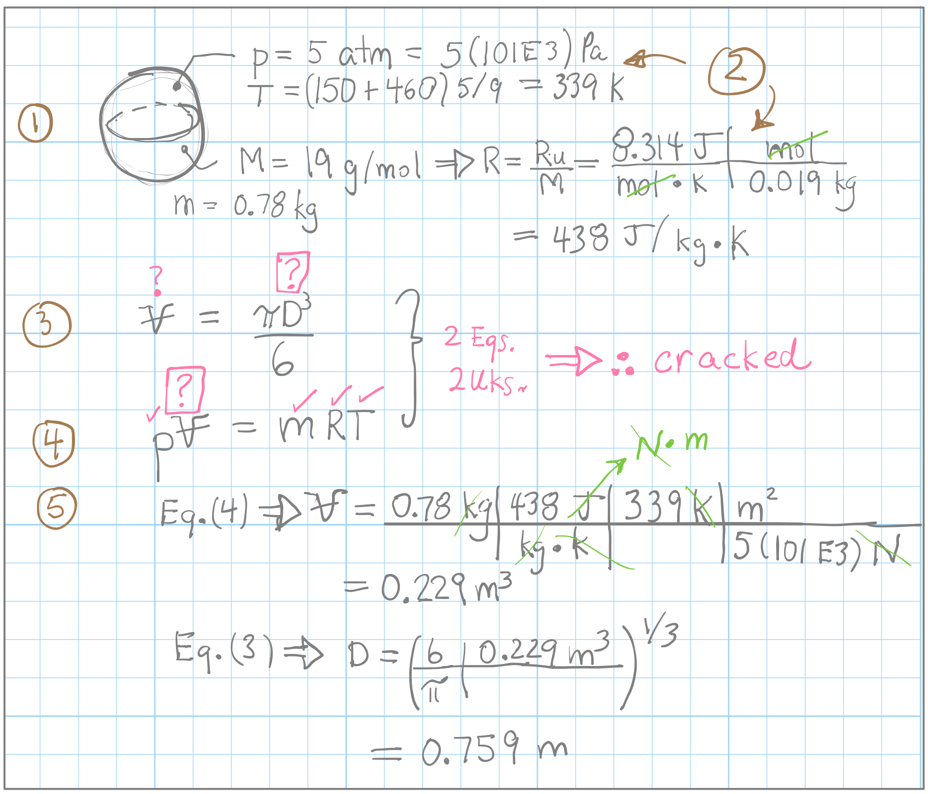
A gas will be held in a spherical tank. The gas can be modeled as an ideal gas. The amount of gas is 780 g. The molar mass is 19 g/mol. The pressure is 4 atm gage. The temperature is 150 °F.

In mm, the diameter of the tank is:
(a) 210 (b) 360 (c) 650 (d) 760 (e) 910

Feedback

Claim: The best choice is (d)

Reasoning:



The steps are:

1. Sketch a situation diagram
2. Covert temperature and pressure to absolute units.
   Convert all units to consistent units.
   Calculate the specific gas constant.
3. Apply the formula for sphere volume
4. Apply the mass form of the IGL
5. Do the calcs

Problem 1.35

The temperature of a gas is 38 °F above room temperature. English units are being used. What magnitude of temperature should be used in the IGL (ideal gas law)?

(a) 38 (b) 108 (c) 198 (d) 568 (e) 643

Feedback

Claim: The best answer is (d)

Reasoning:

① $T = (38 + 70)\ ^\circ F = 108\ ^\circ F$

② $T = (460^\circ + 108^\circ) = 568\ ^\circ F$

Assume that room temperature is 70 °F. Then, take the following steps.

1. Convert differential temperature to Fahrenheit.
2. Convert to absolute temperature which is the Rankine scale when English units are being used.