Solutions Manual for Fundamentals of Thermodynamics 11th Edition by Borgnakke

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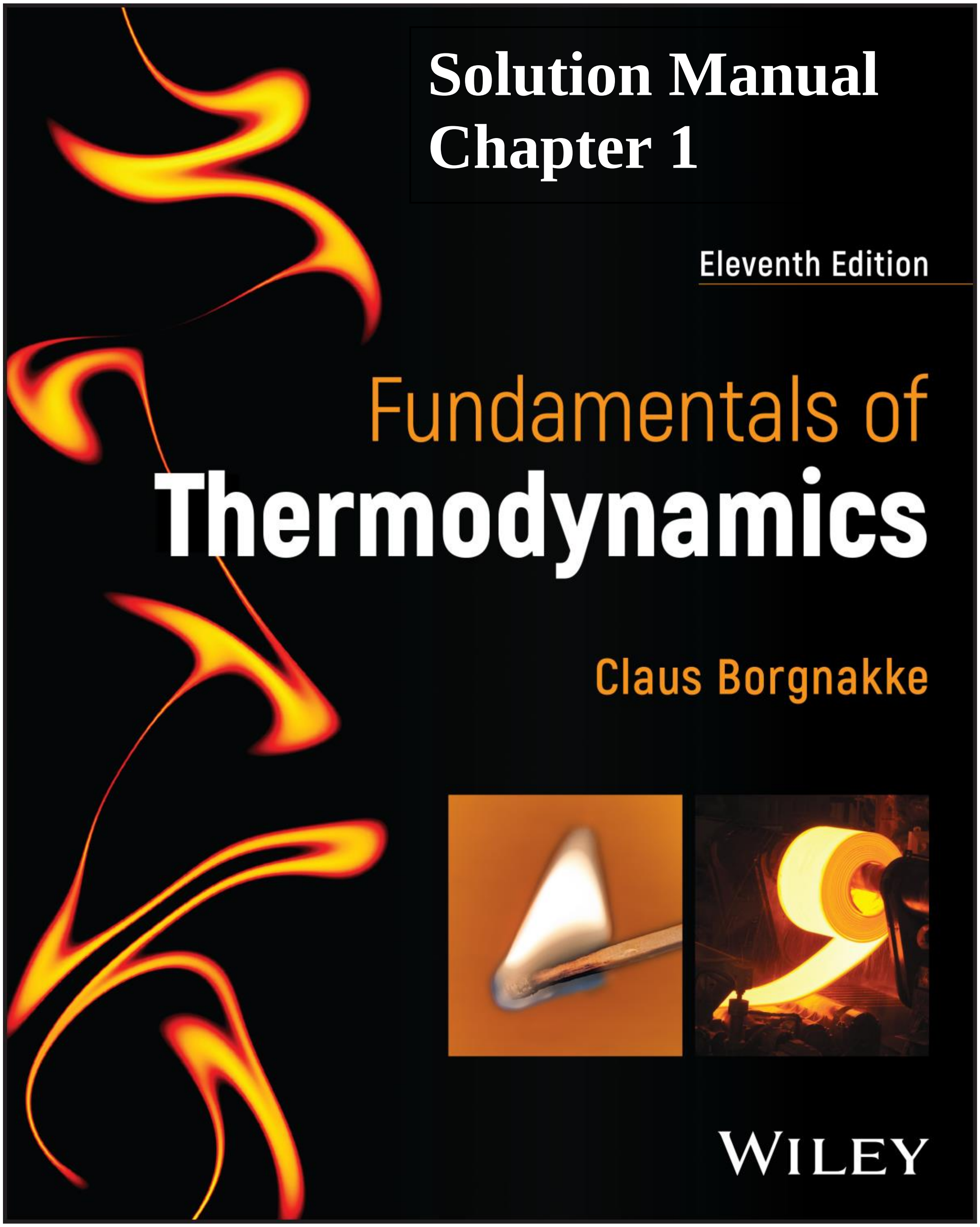
Solution Manual
Chapter 1
Eleventh Edition
Fundamentals of
Thermodynamics
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WILEY

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CONTENT CHAPTER 1

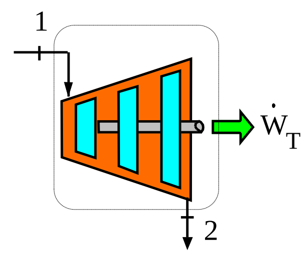
In-Text Concept Questions

1.a

Make a control volume around the turbine in the steam power plant in Fig. 1.2 and list the flows of mass and energy that are there.

Solution:

We see hot high pressure steam flowing in at state 1 from the steam drum through a flow control (not shown). The steam leaves at a lower pressure to the condenser (heat exchanger) at state 2. A rotating shaft gives a rate of energy (power) to the electric generator set.

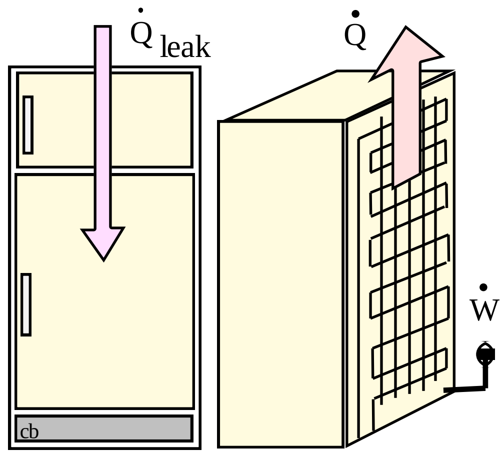


1.b

Take a control volume around your kitchen refrigerator and indicate where the components shown in Figure 1.3 are located and show all flows of energy transfers.

Solution:

The valve and the cold line, the evaporator, is inside close to the inside wall and usually a small blower distributes cold air from the freezer box to the refrigerator room.



The black grille in the back or at the bottom is the condenser that gives heat to the room air.

The compressor sits at the bottom.

1.c

Why do people float high in the water when swimming in the Dead Sea as compared with swimming in a fresh water lake?

As the dead sea is very salty its density is higher than fresh water density. The buoyancy effect gives a force up that equals the weight of the displaced water. Since salt water density is higher the displaced volume is smaller for the same force.

$$F = m_{H2O\ salt}\ g - m_{H2O\ fresh}\ g = (\rho V)_{H2O\ salt}\ g - (\rho V)_{H2O\ fresh}\ g$$

1.d

Density of liquid water is $\rho = 1008 - T/2$ [kg/m^3] with T in °C. If the temperature increases, what happens to the density and specific volume?

Solution:

The density is seen to decrease as the temperature increases.

$$\Delta\rho = -\Delta T/2$$

Since the specific volume is the inverse of the density $v = 1/\rho$ it will increase.

1.e

A car tire gauge indicates 195 kPa; what is the air pressure inside?

The pressure you read on the gauge is a gauge pressure, ΔP, so the absolute pressure is found as

$$P = P_o + \Delta P = 101 + 195 = 296 \text{ kPa}$$

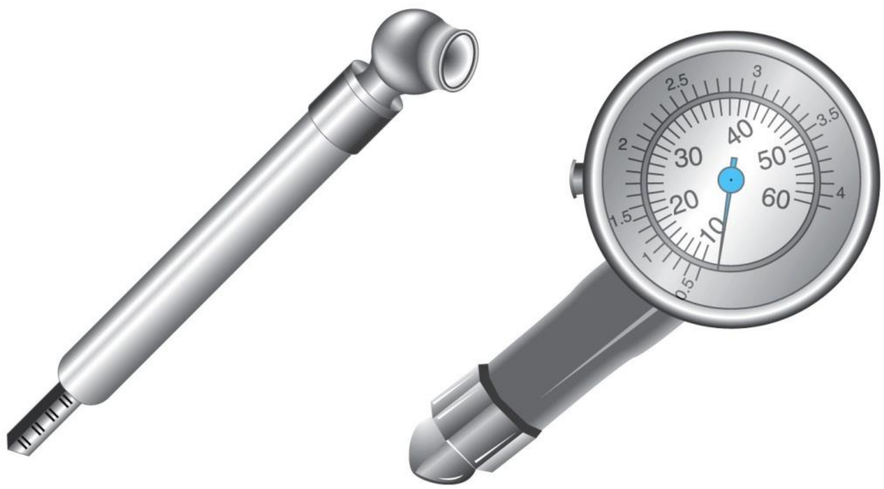


Figure 1.21
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1.f

Can I always neglect ΔP in the fluid above location A in figure 1.13? What does that depend on?

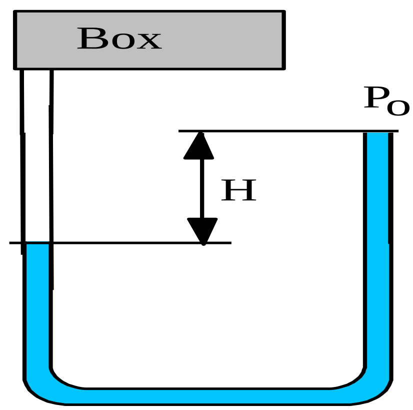
If the fluid density above A is low relative to the manometer fluid then you neglect the pressure variation above position A, say the fluid is a gas like air and the manometer fluid is like liquid water. However, if the fluid above A has a density of the same order of magnitude as the manometer fluid then the pressure variation with elevation is as large as in the manometer fluid and it must be accounted for.

1.g

A U tube manometer has the left branch connected to a box with a pressure of 110 kPa and the right branch open. Which side has a higher column of fluid?

Solution:

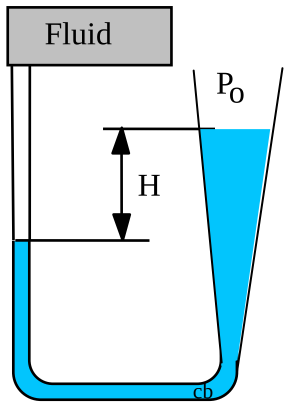
Since the left branch fluid surface feels 110 kPa and the right branch surface is at 100 kPa you must go further down to match the 110 kPa. The right branch has a higher column of fluid.



1.h

If the right side pipe section in Fig. 1.13 is V shaped like a funnel does that change the pressure at location B?

The shape does not affect the pressure only depth from surface at P_o matters.



Comment: the slanted surface has a component of the pressure (normal to the surface) that points upwards.

1.i

If the cylinder pressure in Ex. 1.3 does not give $F_{net} = 0$ what happens?

If: $F_{net} = ma \neq 0 \quad \Rightarrow \quad a \neq 0$

The piston will accelerate up if $P_{cyl} > 250$ kPa given F = 932.9 N
or down up if $P_{cyl} < 250$ kPa given F = 932.9 N which changes the cylinder volume. Thus by controlling the pressure you can move the piston, which is the basis for the hydraulic cylinder used in a bulldozer, a backhoe or front loader.

Concept Problems

1.1

Separate the list *P*, *F*, *V*, *v*, ρ, *T*, *a*, *m*, *L*, *t*, and **V** into intensive, extensive, and non-properties.

Solution:

Intensive properties are independent upon mass: P, v, ρ, T
Extensive properties scales with mass: V, m
Non-properties: F, *a*, L, t, **V**

Comment: You could claim that acceleration *a* and velocity **V** are physical properties for the dynamic motion of the mass, but not thermal properties.

1.2

A tray of liquid water is placed in a freezer where it cools from 20°C to -5°C. Show the energy flow(s) and storage and explain what changes.

Inside the freezer box, the walls are very cold as they are the outside of the evaporator, or the air is cooled and a small fan moves the air around to redistribute the cold air to all the items stored in the freezer box. The fluid in the evaporator absorbs the energy and the fluid flows over to the compressor on its way around the cycle, see Fig. 1.3. As the water is cooled it eventually reaches the freezing point and ice starts to form. After a significant amount of energy is removed from the water it is turned completely into ice (at 0°C) and then cooled a little more to -5°C. The water has a negative energy storage and the energy is moved by the refrigerant fluid out of the evaporator into the compressor and then finally out of the condenser into the outside room air.

1.3

The overall density of fibers, rock wool insulation, foams and cotton is fairly low. Why is that?

Solution:

All these materials consist of some solid substance and mainly air or other gas. The volume of fibers (clothes) and rockwool that is a solid substance is low relative to the total volume that includes air. The overall density is

$$\rho = \frac{m}{V} = \frac{m_{solid} + m_{air}}{V_{solid} + V_{air}}$$

where most of the mass is the solid and most of the volume is air. If you talk about the density of the solid only, it is high.

1.4

Is density a unique measure of mass distribution in a volume? Does it vary? If so, on what kind of scale (distance)?

Solution:

Density is an average of mass per unit volume and we sense if it is not evenly distributed by holding a mass that is more heavy in one side than the other. Through the volume of the same substance (say air in a room) density varies only little from one location to another on scales of meter, cm or mm. If the volume you look at has different substances (air and the furniture in the room) then it can change abruptly as you look at a small volume of air next to a volume of hardwood.

Finally if we look at very small scales on the order of the size of atoms the density can vary infinitely, since the mass (electrons, neutrons and positrons) occupy very little volume relative to all the empty space between them.

1.5

Water in nature exists in different phases such as solid, liquid and vapor (gas). Indicate the relative magnitude of density and specific volume for the three phases.

Solution:

Values are indicated in Figure 1.8 as density for common substances. More accurate values are found in Tables A.3, A.4 and A.5

Water as solid (ice) has density of around 900 kg/m^3

Water as liquid has density of around 1000 kg/m^3

Water as vapor has density of around 1 kg/m^3 (sensitive to P and T)

1.6

What is the approximate mass of 1 L of gasoline? Of helium in a balloon at T_o, P_o?

Solution:

Gasoline is a liquid slightly lighter than liquid water so its density is smaller than 1000 kg/m^3. 1 L is 0.001 m^3 which is a common volume used for food items. A more accurate density is listed in Table A.3 as 750 kg/m^3 so the mass becomes

$$m = \rho V = 750 \text{ kg/m}^3 \times 0.001 \text{ m}^3 = \mathbf{0.75 \text{ kg}}$$

The helium is a gas highly sensitive to P and T, so its density is listed at the standard conditions (100 kPa, 25°C) in Table A.5 as $\rho = 0.1615$ kg/m^3,

$$m = \rho V = 0.1615 \text{ kg/m}^3 \times 0.001 \text{ m}^3 = 1.615 \times 10^{-4} \text{ kg}$$

1.7

You must mail 100 cm^3 of copper (Cu), how heavy a package is that?

Solution:

The density of copper is 8300 kg/m^3 from Table A.3. Therefore the mass is

$$m = \rho V = 8300 \text{ kg/m}^3 \times 100 \text{ cm}^3 = 8300 \text{ kg} \times 100 \text{ (cm/m)}^3$$

$$\mathbf{= 0.83 \text{ kg} = 830 \text{ g}}$$

1.8

A heavy refrigerator has four height-adjustable feet. What feature of the feet will ensure that they do not make dents in the floor?

Answer:
The area that is in contact with the floor supports the total mass in the gravitational field.

$$F = PA = mg$$

so for a given mass the smaller the area is the larger the pressure becomes.

1.9

A swimming pool has an evenly distributed pressure at the bottom. Consider a stiff steel plate lying on the ground. Is the pressure below it just as evenly distributed?

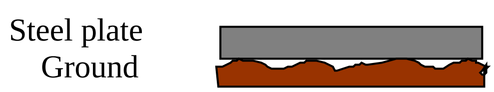
Solution:

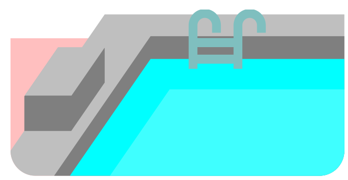
The pressure is force per unit area from Eq. 1.3:

$$P = F/A = mg/A$$

The steel plate can be reasonable plane and flat, but it is stiff and rigid. However, the ground is usually uneven so the contact between the plate and the ground is made over an area much smaller than the actual plate area. Thus the local pressure at the contact locations is much larger than the average indicated above.

The pressure at the bottom of the swimming pool is very even due to the ability of the fluid (water) to have full contact with the bottom by deforming itself. This is the main difference between a fluid behavior and a solid behavior.





1.10

If something floats in water, what does it say about its density?

Solution:

The density must be less than the density of the water.

1.11

Two divers swim at 20 m depth. One of them swims right in under a supertanker; the other stays away from the tanker. Who feels a greater pressure?

Solution:

Each one feels the local pressure which is the static pressure only a function of depth.

$$P_{ocean} = P_0 + \Delta P = P_0 + \rho g H$$

So they feel exactly the same pressure.

1.12

An operating room has a positive gage pressure, whereas an engine test cell has a vacuum; why is that?

Solution:

For the operating room any air leak should be out so there will not be a chance that any microbes or other matter could come in from the outside and contaminate the patient.

For the engine test cell you do not want any leak of fuel, oil fumes or exhaust gasses to go out. They are exhausted by a fan to the outside where they will be highly diluted. If in a manufacturing situation you exhaust large amounts of fumes (like in a paint operation or chemical process) the fumes must be burned in an incinerator (thermal oxidicer) before exhausted to the outside.

1.13

Mention some reasons to have hydraulic cylinders and some reasons to have pneumatic cylinders for motion activation.

Hydraulic cylinders are used when you want to have a large pressure in a cylinder. The hydraulic fluid is a liquid typically one that does not corrode the cylinder/piston walls. Used for cylinders in bulldozers, backhoes, tractors and equipment where you transmit large forces by a shaft over relatively short distances.

Pneumatic cylinders uses a gas typically air to activate a piston. Used for lower pressure applications like motion of a door, flap or contact in control equipment. It is typical for a manufacturing facility to have pressurized air distributed to all working stations or places. It is economical and easier to deal with than the high pressure liquid except you must make sure the air is dried so water vapor cannot condense. Since air is highly compressible it is ill suited to the high pressure applications.

1.14

A water skier does not sink too far down in the water if the speed is high enough. What makes that situation different from our static pressure calculations?

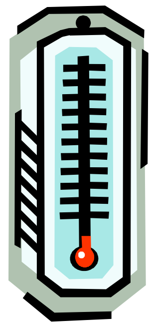
The water pressure right under the ski is not a static pressure but a static plus dynamic pressure that pushes the water away from the ski. The faster you go, the smaller the amount of water is displaced, but at a higher velocity which requires a greater force as the water must accelerated significantly to be moved away.

1.15

What is the lowest temperature in degrees Celsuis? In degrees Kelvin?

Solution:

The lowest temperature is absolute zero which is at zero degrees Kelvin at which point the temperature in Celsius is negative



$$T_K = 0 \text{ K} = -273.15°\text{C}$$

1.16

How cold can it be on Earth and in empty space?

Solution:

The coldest place on earth is the South Pole

Winter average: T = – 60°C

Summer average: T = – 28°C

Empty space

About 3 K caused by background radiation. It obviously depends on where you are.

1.17

A thermometer that indicates the temperature with a liquid column has a bulb with a larger volume of liquid, why is that?

Solution:

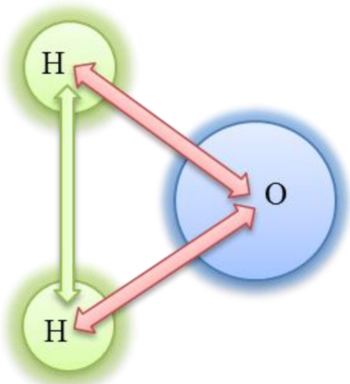
The expansion of the liquid volume with temperature is rather small so by having a larger volume expand with all the volume increase showing in the very small diameter column of fluid greatly increases the signal that can be read.

1.18

How can you illustrate the binding energy between the three atoms in water as they sit in a tri-atomic water molecule. Hint: imagine what must happen to create three separate atoms.

Answer:

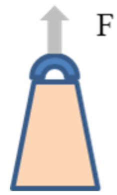
If you want to separate the atoms you must pull them apart. Since they are bound together with strong forces (like non-linear springs) you apply a force over a distance which is work (energy in transfer) to the system and you could end up with two hydrogen atoms and one oxygen atom far apart so they no longer have strong forces between them. If you do not do anything else the atoms will sooner or later recombine and release all the energy you put in and the energy will come out as radiation or given to other molecules by collision interactions.



Properties, Units, and Force

1.19

One kilopond (1 kp) is the weight of 1 kg in the standard gravitational field. How many Newtons (N) is that?



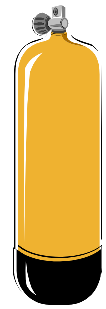
$F = ma = mg$

$1\ \text{kp} = 1\ \text{kg} \times 9.807\ \text{m/s}^2 = \mathbf{9.807\ N}$

1.20

A fuel container has 1/3 kmol of ethanol and 1/4 kmol of methanol. What is the total mass of fuel?

Table A.5: $M_{ethanol} = 46.069$; $M_{methanol} = 32.042$



$$m_{ethanol} = n_{eth.} M_{eth.} = \frac{1}{3} \times 46.069 = 15.356 \text{ kg}$$

$$m_{methanol} = n_{meth.} M_{meth.} = \frac{1}{4} \times 32.042 = 8.0105 \text{ kg}$$

$$m_{tot} = m_{eth.} + m_{meth.} = 15.356 + 8.0105 = \mathbf{23.337 \text{ kg}}$$

1.21

A steel cylinder of mass 4 kg contains 4 L of dry sand at 25°C at 100 kPa. Find the total mass and volume of the system. List two extensive and three intensive properties of the sand.

Solution:

Density of steel in Table A.3: $\rho = 7820 \text{ kg/m}^3$

Volume of steel: $V = m/\rho = \dfrac{4 \text{ kg}}{7820 \text{ kg/m}^3} = 0.000\,512 \text{ m}^3$

Density of sand in Table A.3: $\rho = 1500 \text{ kg/m}^3$

Mass of sand: $m = \rho V = 1500 \text{ kg/m}^3 \times 0.004 \text{ m}^3 = 6 \text{ kg}$

Total mass: $m = m_{steel} + m_{sand} = 4 + 6 = \mathbf{10\ kg}$

Total volume: $V = V_{steel} + V_{sand} = (0.000\,512 + 0.004) \text{ m}^3$

$= \mathbf{0.004\,512\ m^3 = 4.51\ L}$

Extensive properties: m, V
Intensive properties: ρ (or $v = 1/\rho$), T, P

1.22

As a clothes washer is nearly done it spins 5 kg of wet clothes with 20 m/s at a radius of 0.3 m. What is the force on the rotating drum?
Hint: acceleration in rotation is $\mathbf{V}^2/r$.

Solution:

$$F_{\text{centrifugal}} = m\,\mathbf{V}^2/r = 5\text{ kg} \times (20\text{ m/s})^2 / 0.3\text{ m}$$
$$= 6667\text{ kg m/s}^2 = \mathbf{6667\ N}$$

1.23

A short freight train moves at 60 km/h with a total mass of 55 tonne and starts to decelerate at a constant rate of 0.5 m/ s^2 to a full stop. What are the force and total time required?

Solution:

$$a = \frac{d\mathbf{V}}{dt} = \frac{\Delta\mathbf{V}}{\Delta t} \quad =>$$

$$\Delta t = \frac{\Delta\mathbf{V}}{a} = \frac{(60 - 0)\ \text{km/h} \times 1000\ \text{m/km}}{3600\ \text{s/h} \times 0.5\ \text{m/s}^2} = \mathbf{33.3\ sec}$$

$$F = ma = 55\ 000\ \text{kg} \times 0.5\ \text{m/s}^2 = \mathbf{27\ 500\ N}$$

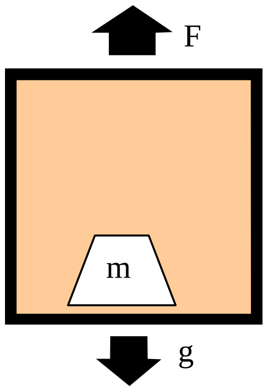
Comment: 55 tonne it is a light load for a freight train.

1.24

At a building site the work elevator has a mass of 550 kg and it has supplies with a total mass of 400 kg. How much force should the cable pull up with to have an acceleration of 1.5 m/s^2 in the upwards direction?

Solution:

The total mass moves upwards with an acceleration plus the gravitations acts with a force pointing down.



$$ma = \sum F = F - mg$$

$$F = ma + mg = m(a + g)$$
$$= (550 + 400)\text{ kg} \times (1.5 + 9.81)\text{ m/s}^2$$
$$= \mathbf{10\ 745\ N}$$

1.25

If a worker, 85 kg, gets on the elevator in the previous problem how much weight does this person feel when the elevator starts moving?

Solution:

The equation of motion is

$$ma = \sum F = F - mg$$

so the force from the floor becomes

$$F = ma + mg = m(a + g)$$
$$= 85 \text{ kg} \times (1.5 + 9.81) \text{ m/s}^2$$
$$= 961.35 \text{ N}$$
$$= x \text{ kg} \times 9.81 \text{ m/s}^2$$

Solve for x

$$x = 961.35 \text{ N}/ 9.81 \text{ m/s}^2 = 9\mathbf{8\ kg}$$

The person then feels like having a mass of 98 kg instead of 85 kg. The weight is really force so to compare to standard mass we should use kp. So in this example the person is experiencing a force of 98 kp instead of the normal 85 kp.

Specific Volume

1.26

A power plant that separates carbon-dioxide from the exhaust gases compresses it to a density of 110 kg/m^3 and stores it in an un-minable coal seam with a porous volume of 100 000 m^3. Find the mass they can store.

Solution:

$$m = \rho V = 110 \text{ kg/m}^3 \times 100\,000 \text{ m}^3 = 11 \times 10^{6} \text{ kg}$$

Comment:
Just to put this in perspective a power plant that generates 2000 MW by burning coal would make about 20 million tons of carbon-dioxide a year. That is 2000 times the above mass so it is nearly impossible to store all the carbon-dioxide being produced.

1.27

A cement mixer should deliver 2 m^3 mix of granite stone, dry sand and water in a mass ratio of 2 to 1 to 1 (cement included with the sand). Use properties from tables A.3 and A.4 and find the mass of each component.

Solution:

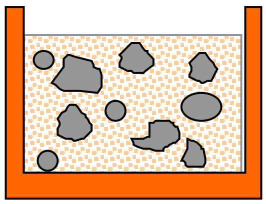
Specific volume and density are ratios of total mass and total volume.

$$m_{TOT} = m_{stone} + m_{sand} + m_{liq} = m_{scale}\,(2 + 1 + 1)$$

$$V_{TOT} = V_{stone} + V_{sand} + V_{liq} = (m/\rho)_{stone} + (m/\rho)_{sand} + (m/\rho)_{liq}$$
$$= m_{scale}\,[(2/\rho)_{stone} + (1/\rho)_{sand} + (1/\rho)_{liq}]$$
$$= m_{scale}\,[\frac{2}{2750} + \frac{1}{1500} + \frac{1}{997}]\,\frac{1}{kg/m^3} = m_{scale} \times 0.002397\,\frac{m^3}{kg}$$

$$m_{scale} = 2\ m^3/(\ 0.002397\,\frac{m^3}{kg}) = 834.4\ kg$$

$$m_{stone} = 2\,m_{scale} = 2 \times 834.4\ kg = 1669\ kg$$
$$m_{sand} = m_{scale} = 834.4\ kg$$
$$m_{liq} = m_{scale} = 834.4\ kg$$



1.28

A container is filled with 1100 kg of granite (density 2400 kg/m^3) together with 5 kg air, with density 1.15 kg/m^3. Find the total volume and the overall (average) specific volume.

Solution:

$$V_{tot} = V_{air} + V_{granite} = m_{air}/\rho_{air} + m_{granite}/\rho_{granite}$$
$$= 5 \text{ kg}/1.15 \text{ kg/m}^3 + 1100 \text{ kg}/2400 \text{ kg/m}^3$$
$$= 4.348 \text{ m}^3 + 0.4583 \text{ m}^3 = \mathbf{4.806\ m^3}$$
$$v = \frac{V}{m} = \frac{4.806}{1100 + 5}\frac{\text{m}^3}{\text{kg}} = \mathbf{0.00435\ m^3/kg}$$

Comment: Because the air and the granite are not mixed or evenly distributed in the container the overall specific volume or density does not have much meaning.

Pressure

1.29

A 5000-kg elephant has a cross sectional area of 0.02 m^2 on each foot. Assuming an even distribution, what is the pressure under its feet?

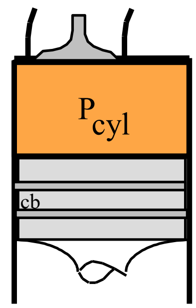
Force balance: $ma = 0 = PA – mg$

$$P = mg/A = 5000 \text{ kg} \times 9.81 \text{ m/s}^2 /(4 \times 0.02 \text{ m}^2)$$
$$= 613\ 125 \text{ Pa} = \mathbf{613\ kPa}$$

1.30

A valve in a cylinder has a cross sectional area of 11 cm^2 with a pressure of 735 kPa inside the cylinder and 99 kPa outside. How large a force is needed to open the valve?

$$F_{net} = P_{in}A - P_{out}A$$
$$= (735 - 99) \text{ kPa} \times 11 \text{ cm}^2$$
$$= 6996 \text{ kPa cm}^2$$
$$= 6996 \times \frac{\text{kN}}{\text{m}^2} \times 10^{-4} \text{ m}^2$$
$$= \mathbf{700\ N}$$



1.31

The piston cylinder in Fig. P1.30 has a diameter of 10 cm, inside pressure 1235 kPa. What is the force holding the massless piston up as the piston lower side has P_0 besides the force?

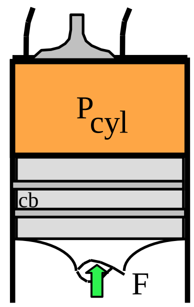
Solution:
Force acting on the mass by the inside pressure

$$F\downarrow = P\ A$$

Force balance: $F\uparrow = F + P_0\ A = F\downarrow \quad => \quad F = (P - P_0)\ A$

$$A = \pi\ D^2\ (1\ /\ 4) = 0.007854\ m^2$$

$$F = (1235 - 101)\ kPa \times 0.007854\ m^2 = \mathbf{8.91\ kN}$$



1.32

A hydraulic lift has a piston diameter of 10 cm. What should the hydraulic fluid pressure be in order to lift a mass of 1250 kg?

Solution:

With the piston at rest the static force balance is

$$F\uparrow = P\ A = F\downarrow = mg$$
$$A = \pi\ r^2 = \pi\ D^2/4 = \pi \times 0.1^2\ m^2/4 = 0.007854\ m^2$$

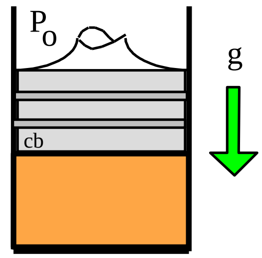
$$PA = mg \qquad \Rightarrow \qquad P = mg/A$$

$$P = \frac{1250 \times 9.81}{0.007854} \frac{kg\ m/s^2}{m^2} = 1561\ 306\ \frac{N}{m^2} = \mathbf{1561\ kPa}$$

1.33

A hydraulic cylinder has a 125-mm diameter piston with an ambient pressure of 1 bar. Assuming standard gravity, find the total mass the piston can lift if the inside hydraulic pressure is 2000 kPa.

Solution:



Force balance:

$$F\uparrow = PA = F\downarrow = P_0A + m\,g;$$

$$P_0 = 1 \text{ bar} = 100 \text{ kPa} = 100 \text{ kN/ m}^2$$

$$= 100 \times 1000 \text{ kg m/s}^2\text{m}^2$$

$$= 100 \times 1000 \text{ kg/ms}^2$$

$$A = (\pi/4)\, D^2 = (\pi/4) \times 0.125^2 \text{ m}^2 = 0.01227 \text{ m}^2$$

$$m = (P - P_0)\,\frac{A}{g} = (\ 2000 - 100\ ) \text{ kPa} \times 1000 \text{ Pa/kPa} \times \frac{0.01227}{9.80665}\,\frac{\text{m}^2}{\text{m/s}^2}$$

$$= \mathbf{2377\ kg}$$

1.34

A 75-kg human footprint is 0.05 m^2 when the human is wearing boots. Suppose you want to walk on snow that can at most support an extra 3 kPa; what should the total snowshoe area be?

Force balance: $ma = 0 = \Delta P\ A - mg$

$$A = \frac{mg}{\Delta P} = \frac{75\text{ kg} \times 9.81\text{ m/s}^2}{3\text{ kPa}} = 0.245\text{ m}^2$$

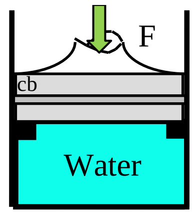
1.35

A piston/cylinder with diameter of 0.11 m has a piston mass of 60 kg plus a force of 700 N resting on the stops, as shown in the figure. With an outside atmospheric pressure of 101 kPa, what should the water pressure be to lift the piston?

Solution:

The force acting down on the piston comes from gravitation and the outside atmospheric pressure acting over the top surface.

Force balance: $F\uparrow = F\downarrow = PA = P_0A + m_pg + F$



Now solve for P
divide by 1000 to convert to kPa for 2^{nd} + 3^{rd} terms

$$A = \pi D^2/4 = \pi \times 0.11^2 \text{ m}^2/4 = 0.0095 \text{ m}^2$$

$$P = P_0 + \frac{m_pg}{A} + F/A$$

$$= 101 \text{ kPa} + \frac{60 \text{ kg} \times 9.80665 \text{ m/s}^2}{0.0095 \text{ m}^2 \times 1000 \text{ Pa/kPa}} + \frac{700 \text{ N}}{0.0095 \text{ m}^2 \times 1000 \text{ Pa/kPa}}$$

$$= 101 \text{ kPa} + 61.94 \text{ kPa} + 73.68 \text{ kPa} = \mathbf{236.6 \text{ kPa}}$$

1.36

A 2.5 m tall steel cylinder has a cross sectional area of 1.5 m^2. At the bottom with a height of 0.5 m is liquid glycol on top of which is a 1.5 m high layer of engine oil shown in Fig. P1.36. The oil surface is exposed to atmospheric air at 101 kPa. What is the pressure at the bottom and at the interphase between the glycol and the oil?

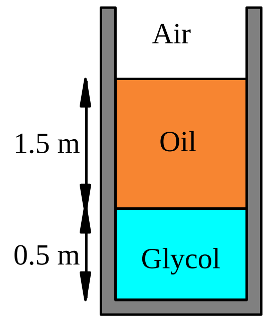
Solution:

The pressure in the fluid goes up with the depth as

$$P = P_{top} + \Delta P = P_{top} + \rho g h$$

and since we have two fluid layers we get

$$P = P_{top} + [(\rho h)_{oil} + (\rho h)_{glycol}]\ g$$



The densities from Table A.4 are:

$$\rho_{glycol} = 1120\ \mathrm{kg/m^3}; \quad \rho_{oil} = 885\ \mathrm{kg/m^3}$$

$$P_{bot} = 101\ \mathrm{kPa} + [885 \times 1.5 + 1120 \times 0.5]\ \mathrm{kg/m^2} \times \frac{9.807}{1000}\ \frac{\mathrm{m/s^2}}{\mathrm{Pa/kPa}}$$

$$= \mathbf{119.5\ kPa}$$

$$P_{int} = 101\ \mathrm{kPa} + 885 \times 1.5\ \mathrm{kg/m^2} \times \frac{9.807}{1000}\ \frac{\mathrm{m/s^2}}{\mathrm{Pa/kPa}} = \mathbf{114\ kPa}$$

1.37

An underwater buoy is anchored at the seabed with a cable, and it contains a total mass of 250 kg in a 0.4 m^3 volume. What is the cable force?

Solution:

We need to do a force balance on the system at rest and the combined pressure over the buoy surface is the buoyancy (lift) equal to the “weight” of the displaced water volume

The buoyancy force is shown in Eq. 1.8 where F_{lift} comes from the pressure distribution around the object.

$$F_{buoyancy} = F_{lift} = m_{H2O}g = \rho_{H2O}Vg$$

$$ma = 0 = m_{H2O}g - mg - F = F_{buoyancy} - F_{gravitation} - F_{cable}$$
$$= \rho_{H2O}Vg - mg - F$$

$$F = (\rho_{H2O}V - m)\ g$$
$$= (997\ kg/m^3 \times 0.4\ m^3 - 250\ kg) \times 9.81\ m/s^2$$
$$= \mathbf{1460\ N}$$

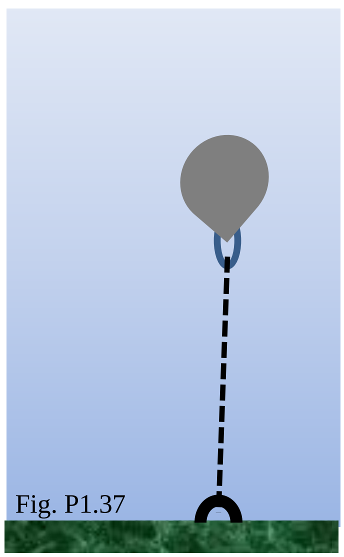


Fig. P1.37

1.38

If an oil rig mass is 20 000 tonnes and the net pull of the cables should be 5000 kN from the seabed, how much water displacement is needed?

Solution:

We need to do a force balance on the system at rest and the combined pressure over the submerged surface is the buoyancy (lift) equal to the "weight" of the displaced water volume

$$ma = 0 = m_{H2O}g - F_{cable} - m_{rig}\, g$$

$$m_{H2O} = (F_{cable} + m_{rig}\, g)/g = F_{cable}/g + m_{rig}$$
$$= 5000 \times 1000 \text{ N}/9.81 \text{ m/s}^2 + 20\,000 \times 1000 \text{ kg}$$
$$= 509.7 \times 1000 \text{ kg} + 20\,000 \times 1000 \text{ kg} = 20.51 \times 10^6 \text{ kg}$$

$$V = m_{H2O}/\rho_{H2O} = 20.51 \times 10^6 \text{ kg} / 997 \text{ kg/m}^3 = \mathbf{20\,600\ m^3}$$

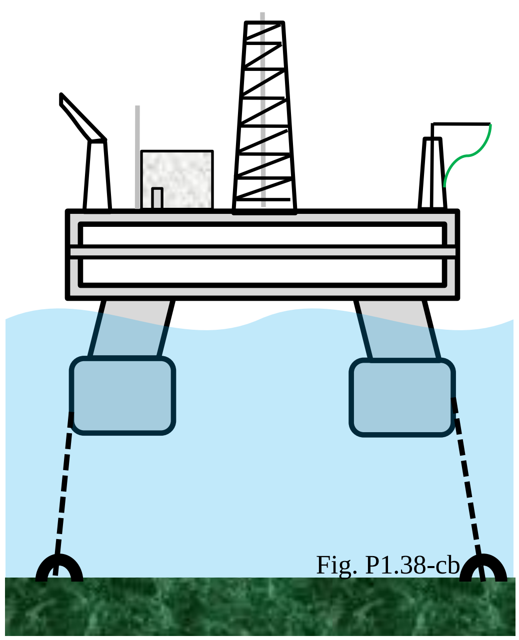


Fig. P1.38-cb

1.39

You go parasailing getting up 55 m in the air and later dive 10 m down in the ocean. Assume the atmospheric pressure is 1025 mbar at the beach, density of the salt water is 1000 kg/m^3 and the air density is 1.18 kg/m^3. What is the pressure each place?

Solution:

$\Delta P = \rho g h$,

Units from A.1: 1 mbar = 100 Pa (1 bar = 100 kPa).

$$P_{para} = P_0 - \Delta P = 1025 \times 100 \text{ Pa} - 1.18 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 55 \text{ m}$$

$$= 1.0186 \times 10^5 \text{ Pa} = \mathbf{101.9\ kPa}$$

$$P_{ocean} = P_0 + \Delta P = 1025 \times 100 \text{ Pa} + 1000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 10 \text{ m}$$

$$= 2.006 \times 10^5 \text{ Pa} = \mathbf{201\ kPa}$$

1.40

A steel tank of cross sectional area 2 m^2 and 13 m tall weighs 10 000 kg and it is open at the top, as shown in Fig. P1.40. We want to float it in the ocean so it sticks 10 m straight down by pouring concrete into the bottom of it. How much concrete should I put in?

Solution:

The force up on the tank is from the water pressure at the bottom times its area. The force down is the gravitation times mass and the atmospheric pressure.

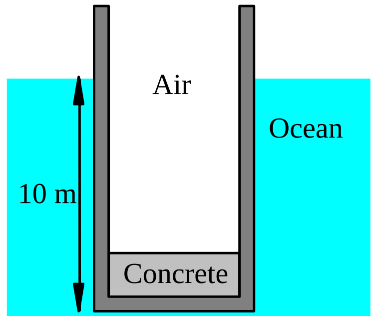


Fig P1.40-cb

$$F\uparrow = PA = (\rho_{ocean}gh + P_0)A$$

$$F\downarrow = (m_{tank} + m_{concrete})g + P_0A$$

The force balance becomes

$$F\uparrow = F\downarrow = (\rho_{ocean}gh + P_0)A = (m_{tank} + m_{concrete})g + P_0A$$

Solve for the mass of concrete

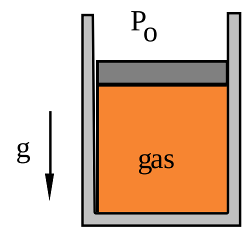
$$m_{concrete} = (\rho_{ocean}hA - m_{tank}) = 997 \text{ kg/ m}^3 \times 10 \text{ m} \times 2 \text{ m}^2 - 10\ 000 \text{ kg}$$
$$= \mathbf{9\ 940\ kg}$$

Notice: The first term is the mass of the displaced ocean water. The force up is the weight (mg) of this mass called buoyancy which balances with gravitation and the force from P_0 cancel.

1.41

A piston, m_p = 5 kg, is fitted in a cylinder, A = 15 cm^2, that contains a gas. The setup is in a centrifuge that creates an acceleration of 25 m/s^2 in the direction of piston motion towards the gas. Assuming standard atmospheric pressure outside the cylinder, find the gas pressure.

Solution:



Force balance: $F\uparrow = F\downarrow = P_0A + m_pg = PA$

$$P = P_0 + \frac{m_pg}{A}$$

$$= 101.325 \text{ kPa} + \frac{5 \times 25}{1000 \times 0.0015} \frac{\text{kPa kg m/s}^2}{\text{Pa m}^2}$$

$= \mathbf{184.7\ kPa}$

1.42

A container ship is 240 m long and 32 m wide. Assume the shape is like a rectangular box. How much mass does the ship carry as load if it is 10 m down in the water and the mass of the ship itself is 30 000 tonnes?

Balance forces

$$F\uparrow = F\downarrow = m_{displ\ H2O}\ g = (m_{ship} + m_{cargo})\ g$$

The displacement volume of water has a mass that equals the total mass of the ship and its cargo.

$$V_{displ} = H\ A = 10\ m \times 240\ m \times 32\ m = 76\ 800\ m^3$$

$$m_{displ\ H2O} = \rho_{ocean}\ V_{displ} = 1000\ kg/\ m^3 \times 76\ 800\ m^3 = 76.8 \times 10^6\ kg$$

The cargo mass then is

$$m_{cargo} = m_{displ\ H2O} - m_{ship} = 76.8 \times 10^6\ kg - 30\ 000\ t$$

$$= (76.8 - 30) \times 10^6\ kg = \mathbf{46.8 \times 10^6\ kg = 46\ 800\ tonnes}$$

Manometers and Barometers

1.43

A probe is lowered 16 m into a lake. Find the absolute pressure there?

Solution:

The pressure difference for a column is from Eq.1.2 and the density of water is from Table A.4.

$$\Delta P = \rho g H$$
$$= 997 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 16 \text{ m}$$
$$= 156\,489 \text{ Pa} = 156.489 \text{ kPa}$$

$$P_{lake} = P_0 + \Delta P$$
$$= 101.325 \text{ kPa} + 156.489 \text{ kPa}$$
$$= \mathbf{257.8\ kPa}$$

1.44

A hang glider is about 22 m^2 for the sail with 45 kg mass plus the person, 75 kg. How large a gage pressure under the sail is needed for level flight? Suppose you accelerate down with 2 m/s^2 how large must the gage pressure then be?

Solution:

Force acting on the mass by the gravitational field at level flight

$$F\downarrow = ma = mg = F\uparrow = (P - P_0)\ A = \Delta P\ A$$

$$\Delta P = F/A = mg/A = (75 + 45)\ kg \times 9.80665\ m/s^2 / 22\ m^2$$
$$= 53.5\ Pa = 0.054\ kPa$$

Flying downwards

$$F\downarrow = m(g - a) = \Delta P\ A$$

$$\Delta P = m(g - a)/A = (75 + 45)\ kg \times (9.80665 - 2)\ m/s^2 / 22\ m^2$$
$$= 42.6\ Pa = 0.043\ kPa$$

Recall 1 Pa = 1 N/m. The kPa matches with F in kN. This assumes an even pressure distribution under the sail. The small ΔP is due to the large sail.

1.45

A vacuum pump keeps a gage pressure of 3.1 cm water column underneath a basement floor to suck out radon gas. What force does that put under a floor of area 20 m^2.

Solution:

$$\Delta P = F/A \quad => \quad F = \Delta P\ A = \rho\ L\ g\ A$$

$$F = 997\ kg/m^3 \times 0.031\ m \times 9.80665\ m/s^2 \times 20\ m^2$$
$$= 6062\ kg\ m/s^2 = \mathbf{6062\ N}$$

Since it is a vacuum it is a force down on the floor.

1.46

A barometer to measure absolute pressure shows a mercury column height of 745 mm. The temperature is such that the density of the mercury is 13 550 kg/m^3. Find the ambient pressure.

Solution:

Hg : $L = 745$ mm $= 0.745$ m; $\rho = 13\,550$ kg/m^3

The external pressure P balances the column of height L so from Fig. 1.14

$$P = \rho L g = 13\,550 \text{ kg/m}^3 \times 9.80665 \text{ m/s}^2 \times 0.745 \text{ m} \times 10^{-3} \text{ kPa/Pa}$$

$= \mathbf{99\ kPa}$

1.47

A differential pressure gauge mounted on a vessel shows 1.25 MPa and a local barometer gives atmospheric pressure as 0.96 bar. Find the absolute pressure inside the vessel.

Solution:

Def. of gauge pressure: $P = P_{gauge} + P_0$

Convert all pressures to units of kPa.

P_{gauge} = 1.25 MPa = 1250 kPa;

P_0 = 0.96 bar = 96 kPa

$P = P_{gauge} + P_0$ = 1250 + 96 = **1346 kPa**

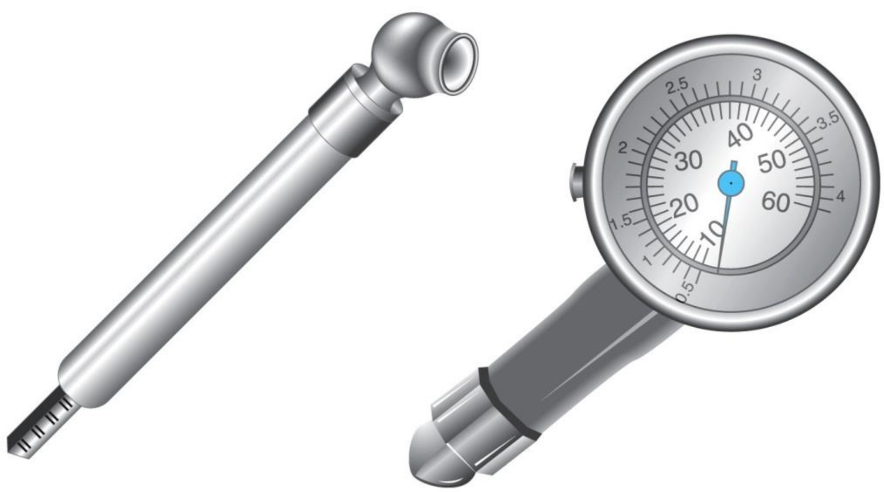


Figure 1.21

1.48

A barometer measures 760 mmHg at street level and 745 mmHg on top of a building. How tall is the building if we assume air density of 1.15 kg/m^3?

Solution:

$$\Delta P = \rho g H$$

$$H = \Delta P/\rho g = \frac{760 - 745}{1.15 \times 9.807} \frac{\text{mmHg}}{\text{kg/m}^2\text{s}^2} \frac{133.32 \text{ Pa}}{\text{mmHg}} = \mathbf{177\ m}$$

Conversion mmHg to Pa in Table A.1

1.49

An exploration submarine should be able to go 2000 m down in the ocean. If the ocean density is 1025 kg/m^3 what is the maximum pressure on the submarine hull?

Solution:

Assume we have atmospheric pressure inside the submarine then the pressure difference to the outside water is

$$\Delta P = \rho L g = (1025 \text{ kg/m}^3 \times 2000 \text{ m} \times 9.807 \text{ m/s}^2) / (1000 \text{ Pa/kPa})$$
$$= 20\ 104 \text{ kPa} = \mathbf{20.1\ MPa}$$

1.50

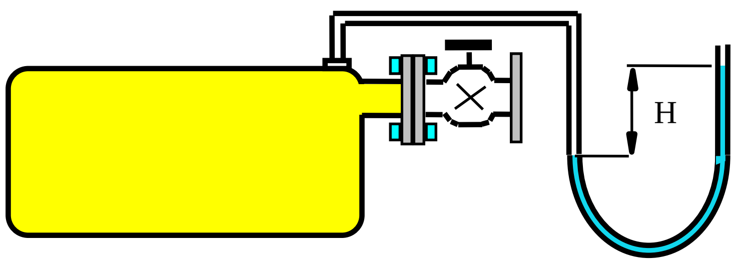
The absolute pressure in a tank is 245 kPa and the local ambient absolute pressure is 101 kPa. If a U-tube with mercury, density 13 550 kg/m^3, is attached to the tank to measure the gage pressure, what column height difference would it show?

Solution:

$$\Delta P = P_{tank} - P_0 = \rho g\ H$$

$$H = (P_{tank} - P_0)/\rho g = [(245 - 101) \times 1000]\ \text{Pa}/(13550\ \text{kg/m}^3 \times 9.81\ \text{m/s}^2)$$

$$= \mathbf{1.08\ m}$$



1.51

An absolute pressure gauge attached to a steel cylinder shows 135 kPa. We want to attach a manometer using liquid water a day that P_{atm} = 101 kPa. How high a fluid level difference must we plan for?

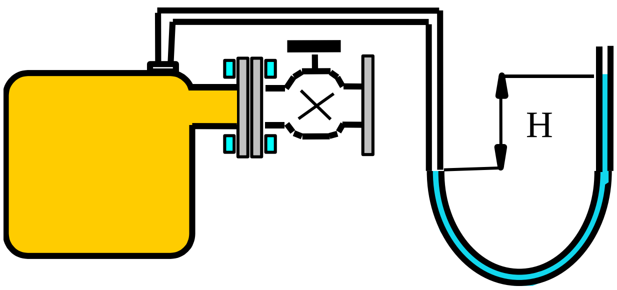
Solution:

Since the manometer shows a pressure difference we have

$$\Delta P = P_{cyl} - P_{atm} = \rho L g$$

$$L = \Delta P / \rho g = \frac{(135 - 101) \text{ kPa}}{997 \text{ kg m}^{-3} \times 9.807 \text{ m/s}^2} \frac{1000 \text{ Pa}}{\text{kPa}}$$

$$= \mathbf{3.48\ m}$$



Comment: You would not use a manometer to measure this, as it is impractical with such a height. A pressure transducer will be used with an electronic readout.

1.52

A pipe flowing light oil has a manometer attached as shown in Fig. P1.52. What is the absolute pressure in the pipe flow?

Solution:

Table A.3: ρ_{oil} = 910 kg/m^3; ρ_{water} = 997 kg/m^3

$$P_{bot} = P_0 + \rho_{water}\, g\, H_{tot} = P_0 + 997\ \text{kg/m}^3 \times 9.807\ \text{m/s}^2 \times 0.8\ \text{m}$$
$$= P_o + 7822\ \text{Pa}$$

$$P_{pipe} = P_{bot} - \rho_{water}\, g\, H_1 - \rho_{oil}\, g\, H_2$$
$$= P_{bot} - 997\ \text{kg/m}^3 \times 9.807\ \text{m/s}^2 \times 0.1\ \text{m}$$
$$-\ 910\ \text{kg/m}^3 \times 9.807\ \text{m/s}^2 \times 0.2\ \text{m}$$
$$= P_{bot} - 977.7\ \text{Pa} - 1784.9\ \text{Pa}$$

$$P_{pipe} = P_o + (7822 - 977.7 - 1784.9)\ \text{Pa}$$
$$= P_o + 5059.4\ \text{Pa} = 101.325 + 5.06 = \mathbf{106.4\ kPa}$$

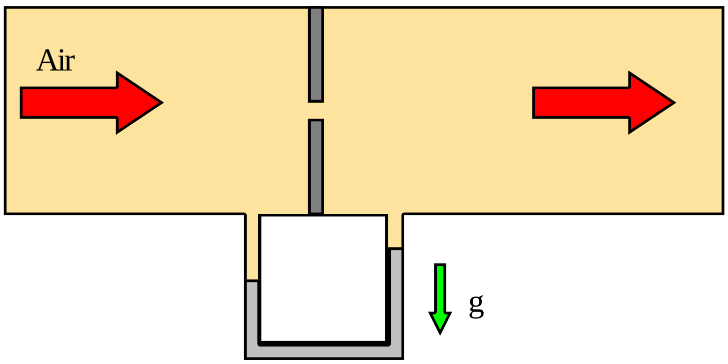
1.53

A piece of experimental apparatus is located where $g = 9.5\ \mathrm{m/s^2}$ and the temperature is 5°C. An air flow inside the apparatus is determined by measuring the pressure drop across an orifice with a mercury manometer (density 13 580 $\mathrm{kg/m^3}$) showing a height difference of 200 mm. What is the pressure drop in kPa?

Solution:

$$\Delta P = \rho g h \ ; \qquad \rho_{Hg} = 13\ 580\ \ \mathrm{kg/m^3}$$

$$\Delta P = 13\ 580\ \mathrm{kg/m^3} \times 9.5\ \mathrm{m/s^2} \times 0.2\ \mathrm{m} = 25802\ \mathrm{Pa} = \mathbf{25.80\ kPa}$$



Energy and Temperature

1.54

A 0.25 m^3 piece of softwood is lifted up to the top shelf in a storage bin that is 4 m above the ground floor. How much increase in potential energy does the wood get?

The potential energy is from Eq.1.5

$$pe = gz$$

and the mass becomes

$$m = \rho\ V = 510\ kg/m^3 \times 0.25\ m^3 = 127.5\ kg$$

$$PE = mgH = 127.5\ kg \times 9.81\ m/s^2 \times 4\ m = 5003\ J = \mathbf{5.0\ kJ}$$

1.55

A racecar of mass 1275 kg travels with a velocity of 20 km/h. Find the kinetic energy. How high should it be lifted in the standard gravitational field to have a potential energy that equals the kinetic energy?

Solution:

Standard kinetic energy of the mass is

$$KE = ½ \text{ m } \mathbf{V}^2 = ½ \times 1275 \text{ kg} \times \left(\frac{20 \times 1000}{3600}\right)^2 \text{ m}^2/\text{s}^2$$

$$= ½ \times 1275 \times 5.5556 \text{ Nm} = 3541.7 \text{ J}$$

$$= \mathbf{3.54\ kJ}$$

Standard potential energy is

POT = mgh

$$h = ½ \text{ m } \mathbf{V}^2 / \text{mg} = \frac{3541.7 \text{ Nm}}{1275 \text{ kg} \times 9.807 \text{ m/s}^2} = \mathbf{0.28\ m}$$

1.56

What is a temperature of –15°C in degrees Kelvin?

Solution:

The offset from Celsius to Kelvin is 273.15 K,
so we get

$$T_K = T_C + 273.15 = -15 + 273.15$$
$$= \mathbf{258.15\ K}$$

1.57

A mercury thermometer measures temperature by measuring the volume expansion of a fixed mass of liquid mercury due to a change in density as

$$\rho_{Hg} = [13595 - 2.5\, T\,]\ \text{kg/ m}^3 \qquad T \ \text{ in Celsius}$$

Find the relative change (%) in volume for a change in temperature from 10°C to 25°C.

From 10°C to 25°C

At 10°C : $\rho_{Hg} = 13595 - 2.5 \times 10 = 13570\ \text{kg/m}^3$

At 25°C : $\rho_{Hg} = 13595 - 2.5 \times 25 = 13532.5\ \text{kg/m}^3$

The volume from the mass and density is: $V = m/\rho$

$$\text{Relative Change} = \frac{V_{25} - V_{10}}{V_{10}} = \frac{(m/\rho_{25}) - (m/\rho_{10})}{m/\rho_{10}}$$

$$= \frac{\rho_{10}}{\rho_{25}} - 1 = \frac{13570}{13532.5} - 1 = 0.0028 \quad \text{or} \quad \mathbf{+0.3\%}$$

1.58

Density of liquid water is $\rho = 1008 - T/2$ [kg/m^3] with T in °C. If the temperature increases 10°C how much deeper does a 1 m layer of water become?

Solution:

The density change for a change in temperature of 10^{o}C becomes

$$\Delta\rho = -\Delta T/2 = -5 \text{ kg/m}^3$$

from an ambient density of

$$\rho = 1008 - T/2 = 1008 - 25/2 = 995.5 \text{ kg/m}^3$$

Assume the area is the same and the mass is the same $m = \rho V = \rho A H$, then we have

$$\Delta m = 0 = V\Delta\rho + \rho\Delta V \quad \Rightarrow \quad \Delta V = -V\Delta\rho/\rho$$

and the change in the height is

$$\Delta H = \frac{\Delta V}{A} = \frac{H\Delta V}{V} = \frac{-H\Delta\rho}{\rho} = 1 \text{ m} \times \frac{-(-5)}{995.5} = \mathbf{0.005\ m}$$

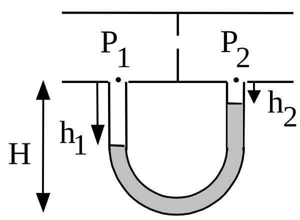
barely measurable.

Review Problems

1.59

Repeat problem 1.53 if the flow inside the apparatus is liquid water, $\rho \cong 1000$ kg/m^3, instead of air. Find the pressure difference between the two holes flush with the bottom of the channel. You cannot neglect the two unequal water columns.

Solution:



Balance forces in the manometer:

$$(H - h_2) - (H - h_1) = \Delta h_{Hg} = h_1 - h_2$$

$$P_1A + \rho_{H_2O}h_1gA + \rho_{Hg}(H - h_1)gA$$
$$= P_2A + \rho_{H_2O}h_2gA + \rho_{Hg}(H - h_2)gA$$

$$\Rightarrow P_1 - P_2 = \rho_{H_2O}(h_2 - h_1)g + \rho_{Hg}(h_1 - h_2)g$$

$$P_1 - P_2 = \rho_{Hg}\Delta h_{Hg}g - \rho_{H_2O}\Delta h_{Hg}g$$
$$= (13\,580 \times 0.2 \times 9.5 - 1000 \times 0.2 \times 9.5\ )\ \text{kg/m}^3 \times \text{m} \times \text{m/s}^2$$
$$= (25\,802 - 1900)\ \text{Pa} = 23\,902\ \text{Pa} = \mathbf{23.9\ kPa}$$

1.60

A dam retains a lake 6 m deep as shown in Fig. P1.60. To construct a gate in the dam we need to know the net horizontal force on a 5 m wide and 6 m tall port section that then replaces a 5 m section of the dam. Find the net horizontal force from the water on one side and air on the other side of the port.

Solution:

$P_{bot} = P_0 + \Delta P$

$\Delta P = \rho g h = 997\ kg/m^3 \times 9.807\ m/s^2 \times 6\ m = 58\ 665\ Pa = 58.66\ kPa$

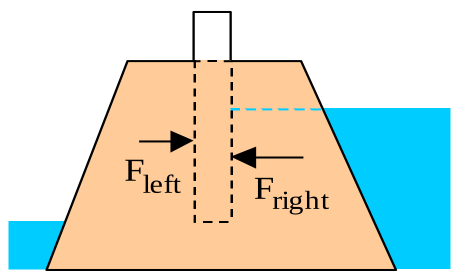
Neglect ΔP in air

$F_{net} = F_{right} - F_{left} = P_{avg}\ A - P_0 A$

$P_{avg} = P_0 + 0.5\ \Delta P$ Since a linear pressure variation with depth.

$F_{net} = (P_0 + 0.5\ \Delta P)A - P_0 A = 0.5\ \Delta P\ A$

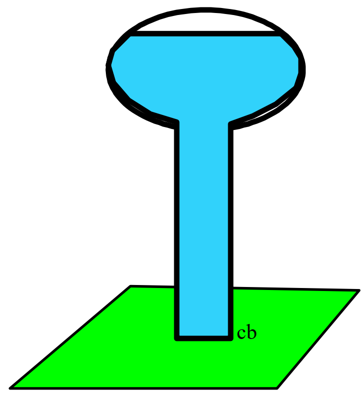
$= 0.5 \times 58.66\ kPa \times 5\ m \times 6\ m =$ **880 kN**



1.61

In the city water tower, water is pumped up to a level 25 m above ground in a pressurized tank with air at 150 kPa over the water surface. This is illustrated in Fig. P1.61. Assuming the water density is 1000 kg/m^3 and standard gravity, find the pressure required to pump more water in at ground level.

Solution:



$\Delta P = \rho\ L\ g$

$= 1000\ \text{kg/m}^3 \times 25\ \text{m} \times 9.807\ \text{m/s}^2$

$= 245\ 175\ \text{Pa} = 245.2\ \text{kPa}$

$P_{bottom} = P_{top} + \Delta P$

$= 150 + 245.2$

$=$ **395 kPa**

1.62

The main waterline into a tall building has a pressure of 600 kPa at 5 m elevation below ground level. How much extra pressure does a pump need to add to ensure a water line pressure of 200 kPa at the top floor 150 m above ground?

Solution:

The pump exit pressure must balance the top pressure plus the column ΔP. The pump inlet pressure provides part of the absolute pressure.

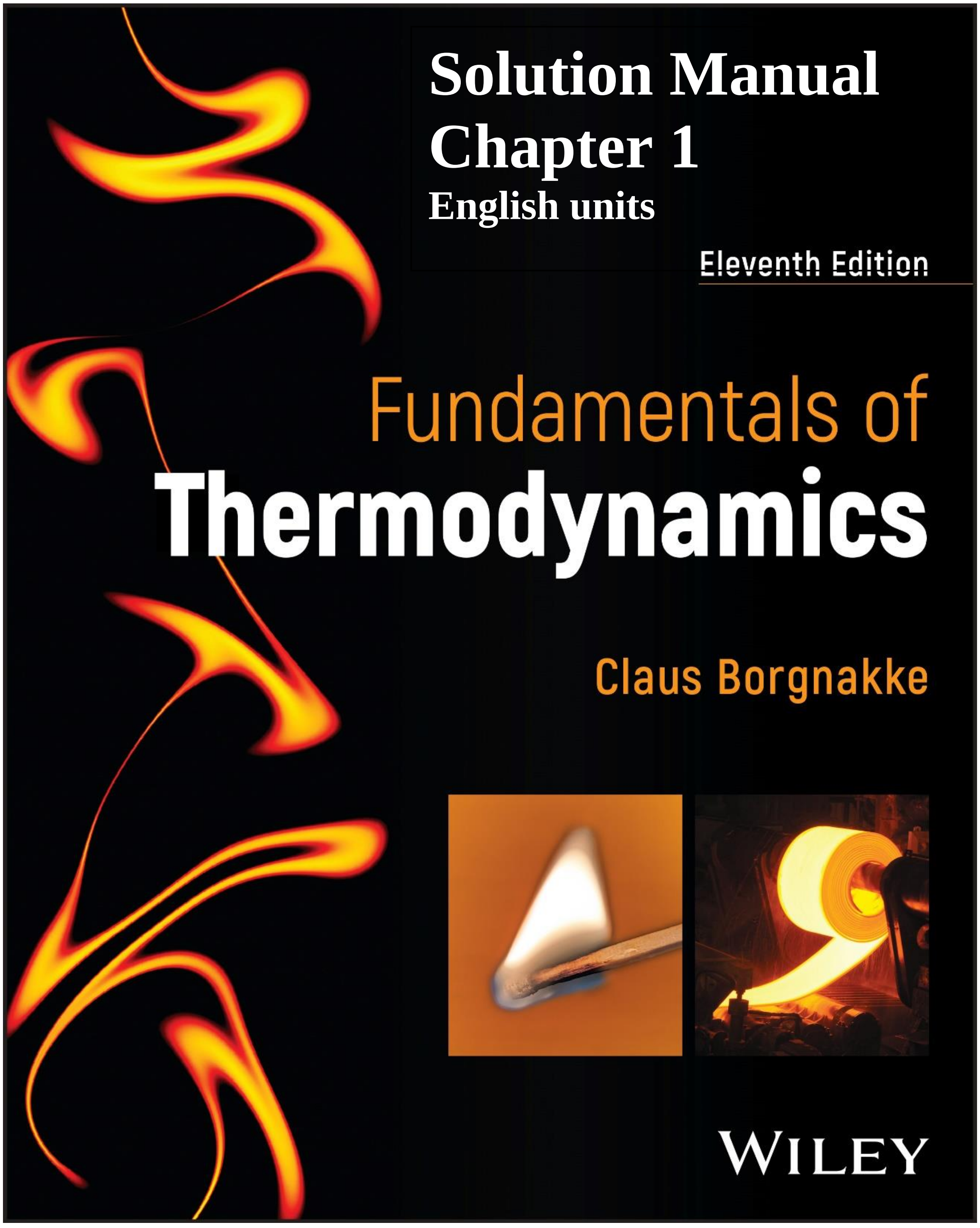
$$P_{\text{after pump}} = P_{\text{top}} + \Delta P$$

$$\Delta P = \rho g h = 997 \text{ kg/m}^3 \times 9.807 \text{ m/s}^2 \times (150 + 5) \text{ m}$$

$$= 1\,515\,525 \text{ Pa} = 1516 \text{ kPa}$$

$$P_{\text{after pump}} = 200 + 1516 = 1716 \text{ kPa}$$

$$\Delta P_{\text{pump}} = 1716 - 600 = \mathbf{1116\ kPa}$$


Solution Manual
Chapter 1
English units
Eleventh Edition
Fundamentals of
Thermodynamics
Claus Borgnakke
WILEY

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Concept Problems

1.63E

A mass of 2 lbm has acceleration of 15 ft/s^2, what is the needed force in lbf?

Solution:

Newtons 2nd law: $F = ma$

$$F = ma = 2 \text{ lbm} \times 15 \text{ ft/s}^2 = 30 \text{ lbm ft/s}^2$$

$$= \frac{30}{32.174} \text{ lbf} = \mathbf{0.932\ lbf}$$

1.64E

How much mass is in 1 gallon of gasoline? If helium in a balloon at atmospheric *P* and *T*?

Solution:

A volume of 1 gal equals 231 in^3, see Table A.1. From Table F.3 the density is 46.8 lbm/ft^3, so we get

$$m = \rho V = 46.8 \text{ lbm/ft}^3 \times 1 \times (231/12^3 \text{) ft}^3 = \mathbf{6.256\ lbm}$$

For the helium we see Table F.4 that density is 10.08×10^{-3} lbm/ft^3 so we get

$$m = \rho V = 10.08 \times 10^{-3} \text{ lbm/ft}^3 \times 1 \times (231/12^3 \text{) ft}^3 = \mathbf{0.00135\ lbm}$$

1.65E

Can you easily carry a one gallon bar of solid gold?

Solution:

The density of solid gold is about 1205 lbm/ft^3 from Table F.2, we could also have read Figure 1.7 and converted the units.

$$V = 1 \text{ gal} = 231 \text{ in}^3 = 231 \times 12^{-3} \text{ ft}^3 = 0.13368 \text{ ft}^3$$

Therefore the mass in one gallon is

$$m = \rho V = 1205 \text{ lbm/ft}^3 \times 0.13368 \text{ ft}^3$$
$$= 161 \text{ lbm}$$

and some people can just about carry that in the standard gravitational field.

1.66E

What is the temperature of –15F in degrees Rankine?

Solution:

The offset from Fahrenheit to Rankine is 459.67 R, so we get

$$T_R = T_F + 459.67 \text{ R} = –15 + 459.67$$
$$= \mathbf{444.67\ R}$$

1.67E

What is the lowest temperature in degrees Fahrenheit you can have? Rankine?

Solution:

The lowest temperature is absolute zero which is at zero degrees Rankine at which point the temperature in Fahrenheit is negative

$$T_R = 0 \text{ R} = -459.67 \text{ F}$$

1.68E

What is the relative magnitude of degree Rankine to degree Kelvin

Look in Table A.1 p. A-6:

$$1 \text{ K} = 1\ ^{o}\text{C} = 1.8 \text{ R} = 1.8 \text{ F}$$

$$1 \text{ R} = \frac{5}{9} \text{ K} = 0.5556 \text{ K}$$

Force, Energy, Density

1.69E

The Rover Explorer has a mass of 410 lbm, how much does this weigh on the Moon ($g = g_{std}/6$) and on Mars where $g = 12.3 \text{ ft/s}^2$

Solution:

Density is mass per unit volume

Moon: $F = mg = 410 \text{ lbm} \times (32.174 / 6) \text{ ft/s}^2 = \mathbf{68.33 \text{ lbf}}$

Mars: $F = mg = 410 \text{ lbm} \times 12.3 \text{ ft/s}^2 = 5043 \text{ lbm ft/s}^2 = \mathbf{156.7 \text{ lbf}}$

The 410 lbm on earth will give a weight of 410 lbf

1.70E

A short freight train moves at 45 mi/h with a total mass of 55 ton and starts to decelerate at a constant 2 ft/s^2 to a full stop. What are the force and the time required?

Solution:

$$a = \frac{d\mathbf{V}}{dt} = \frac{\Delta\mathbf{V}}{\Delta t} \;\Rightarrow\; \Delta t = \frac{\Delta\mathbf{V}}{a}$$

$$\Delta t = \frac{45 \text{ mi/h} \times 1609.34 \text{ m/mi} \times 3.28084 \text{ ft/m}}{3600 \text{ s/h} \times 2 \text{ ft/s}^2} = \mathbf{33\ sec}$$

$$F = ma = 55 \times 2000 \text{ lbm} \times 2 \text{ ft/s}^2 / (32.174 \text{ lbm ft /lbf-s}^2\,)$$

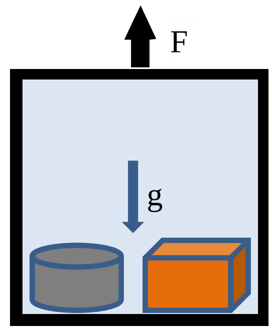
$$= \mathbf{6838\ lbf}$$

1.71E

A building site elevator brings material with mass 900 lbm and a 800 lbm cage up with an acceleration of 3 ft/s^2. What is the needed force in the cable?

Solution:

The total mass moves upwards with an acceleration plus the gravitations acts with a force pointing down.



$$ma = \sum F = F - mg$$

$$F = ma + mg = m(a + g)$$
$$= (900 + 800)\ \text{lbm} \times (3 + 32.174)\ \text{ft/s}^2$$
$$= \mathbf{59\ 796\ lbm\ ft/s^2 = 1859\ lbf}$$

1.72E

A car of mass 4000 lbm travels with a velocity of 60 mi/h. Find the kinetic energy. How high should the car be lifted in the standard gravitational field to have a potential energy that equals the kinetic energy?

Solution

$$\text{KIN} = 0.5\ \text{m}\ \mathbf{V}^2 = 0.5 \times 4000\ \text{lbm} \times \left[\frac{60\ \text{mi/h} \times 1609.3\ \text{m/mi}}{3600\ \text{s/h} \times 0.3048\ \text{m/ft}}\right]^2$$

$$= 15\ 487\ 153\ \text{lbm ft}^2/\text{s}^2 = \mathbf{618.6\ Btu}$$

$$\text{POT} = \text{mgH} \quad => \quad \text{H} = \text{POT/mg} = \frac{15\ 487\ 153\ \text{lbm ft}^2/\text{s}^2}{4000\ \text{lbm} \times 32.174\ \text{ft/s}^2} = \mathbf{120.3\ ft}$$

1.73E

A powerplant that separates carbon-dioxide from the exhaust gases compresses it to a density of 8 lbm/ft^3 and stores it in an un-minable coal seam with a porous volume of 3 500 000 ft^3. Find the mass they can store.

Solution:

$$m = \rho V = 8 \text{ lbm/ft}^3 \times 3\,500\,000 \text{ ft}^3 = 2.8 \times 10^7 \text{ lbm}$$

Just to put this in perspective a power plant that generates 2000 MW by burning coal would make about 44 billion pounds of carbon-dioxide a year. That is 1500 times the above mass so it is nearly impossible to store all the carbon-dioxide being produced.

1.74E

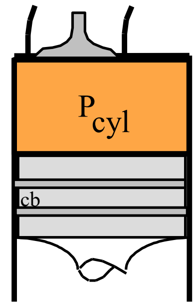
The piston cylinder in Fig. P1.30 has a diameter of 4 in., inside pressure of 100 psia. What force must hold the massless piston up as the piston lower side has P_o besides the force?

$$F_{net} = P_{in}A - P_{out}A$$

$$= (100 - 14.7) \text{ psia} \times \pi \times 2^2 \text{ in}^2$$

$$= 1071.9 \text{ psi} \times \text{in}^2$$

$$= \mathbf{1072\ lbf}$$



1.75E

A laboratory room keeps a vacuum of 1 in. of water due to the exhaust fan. What is the net force on a door of size 6 ft by 3 ft?

Solution:

The net force on the door is the difference between the forces on the two sides as the pressure times the area

$$F = P_{outside}\ A - P_{inside}\ A = \Delta P \times A$$
$$= 1 \text{ in } H_2O \times 6 \text{ ft} \times 3 \text{ ft}$$
$$= 1 \times 0.036126 \text{ lbf/in}^2 \times 18 \text{ ft}^2 \times 144 \text{ in}^2/\text{ft}^2$$
$$= \mathbf{93.64\ lbf}$$

Table A.1: 1 in. H_2O is 0.036 126 lbf/in^2, lbf/in^2 is also often listed as psi.

1.76E

A person, 175 lbm, wants to hoover on a 4 lbm skateboard of size 2 ft by 0.8 ft. How large a gauge pressure under the board is needed?

Solution:

Force acting on the mass by the gravitational field

$$F\downarrow = ma = mg = F\uparrow = (P - P_0) A = \Delta P\ A$$

$$\Delta P = F/A = mg/A = (175 + 4)\text{ lbm} \times 32.174\text{ ft/s}^2 / (2\text{ ft} \times 0.8\text{ ft})$$

$$= 179\text{ lbf}/ 1.6\text{ ft}^2 = (111.9 / 144)\text{ lbf/in}^2 = \mathbf{0.777\ psi}$$

Recall 1 lbf = 32.174 lbm ft/s^2.

1.77E

If an oil rig mass is 20 000 ton and the net pull of the cables should be 1.1×10^6 lbf from the seabed, how much water displacement is needed?

Solution:

We need to do a force balance on the system at rest and the combined pressure over the submerged surface is the buoyancy (lift) equal to the “weight” of the displaced water volume

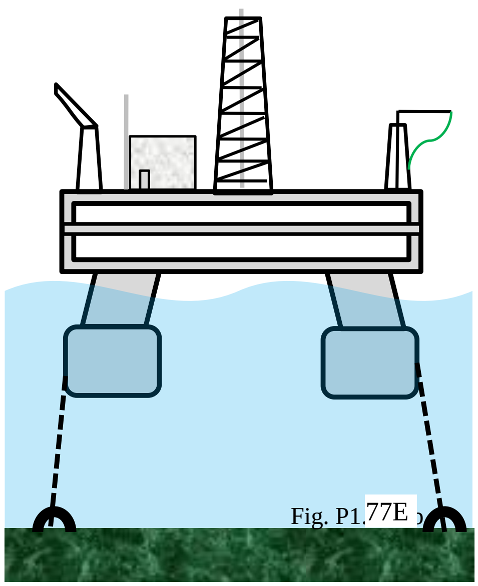
$$ma = 0 = m_{H2O}g - F - m_{rig}g = \rho_{H2O}Vg - F - m_{rig}g$$

$$V = (F + m_{rig}g)/\rho_{H2O}g$$

$$= (1.1 \times 10^6 + 20\,000 \times 2000)\text{ lbf} / (32.174\text{ ft/s}^2 \times 62.2\text{ lbm/ft}^3)$$

$$= \mathbf{20\,537\ ft^3}$$

Recall 1 lbf = 32.174 lbm ft/s^2, 1 ton = 2000 lbm



1.78E

A container ship is 790 ft long and 100 ft wide. Assume the shape is like a rectangular box. How much mass does the ship carry as load if it is 30 ft down in the water and the mass of the ship itself is 30 000 tons?

Balance forces

$$F\uparrow = F\downarrow = m_{displ\ H2O}\ g = (m_{ship} + m_{cargo})\ g$$

The displacement volume of water has a mass that equals the total mass of the ship and its cargo.

$$V_{displ} = H\ A = 30\ ft \times 790\ ft \times 100\ ft = 2\ 370\ 000\ ft^3$$

$$m_{displ\ H2O} = \rho_{ocean}\ V_{displ} = 62.2\ lbm/\ ft^3 \times 2\ 370\ 000\ ft^3 = 147.4 \times 10^6\ lbm$$

The cargo mass then is

$$m_{cargo} = m_{displ\ H2O} - m_{ship} = 147.4 \times 10^6\ lbm - 30\ 000 \times 2000\ lbm$$

$$= (147.4 - 60) \times 10^6\ lbm = \mathbf{87.4 \times 10^6\ lbm = 43\ 700\ tons}$$

1.79E

A manometer shows a pressure difference of 3.5 in. of liquid mercury. Find ΔP in psi.

Solution:

Hg: L = 3.5 in; ρ = 848 lbm/ft^3 from Table F.3

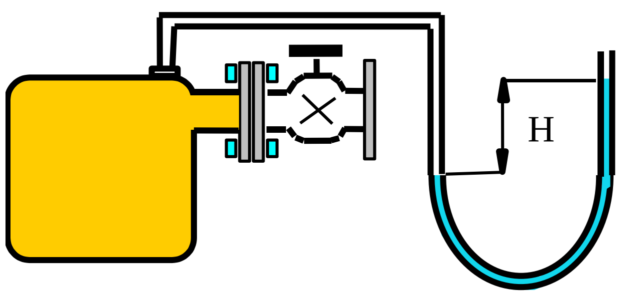
Pressure: 1 psi = 1 lbf/ in^2

The pressure difference ΔP balances the column of height L so from Eq.2.2

$$\Delta P = \rho\, g\, L = 848 \text{ lbm/ft}^3 \times 32.174 \text{ ft/s}^2 \times (3.5/12) \text{ ft}$$

$$= 247.3 \text{ lbf/ft}^2 = (247.3 / 144) \text{ lbf/in}^2$$

$$= \mathbf{1.72\ psi}$$



1.80E

What pressure difference does a 300-ft column of atmospheric air show?

Solution:

Air: L = 300 ft; ρ = 0.073 lbm/ft^3 from Table F.4

The pressure difference ΔP balances the column of height L so from Eq.1.2

$$\Delta P = \rho\, g\, L = 0.073 \text{ lbm/ft}^3 \times 32.1741 \text{ fts}^{-2} \times 300 \text{ ft} = 21.9 \text{ lbf/ft}^2$$
$$= (\ 21.9 / 144) \text{ lbf/in}^2 = \mathbf{0.152\ psi}$$

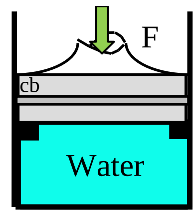
1.81E

A piston/cylinder with cross-sectional area of 0.1 ft^2 has a piston mass of 100 lbm and a force of 180 lbf resting on the stops, as shown in Fig. P1.35. With an outside atmospheric pressure of 1 atm, what should the water pressure be to lift the piston?

Solution:

The force acting down on the piston comes from gravitation and the outside atmospheric pressure acting over the top surface.

Force balance: $F\uparrow = F\downarrow = PA = m_p g + P_0 A + F$



Now solve for P (multiply by 144 to convert from ft^2 to in^2)

$$P = P_0 + \frac{m_p g}{A} + F/A$$

$$= 14.696 \text{ psia} + \frac{100 \times 32.174}{0.1 \times 144 \times 32.174} \text{ psi} + 180 \text{ lbf} /(144 \times 0.1) \text{ in}^2$$

$$= 14.696 \text{ psia} + 6.944 \text{ psi} + 12.5 \text{ psi} = \mathbf{34.14\ lbf/in^2}$$

1.82E

The main waterline into a tall building has a pressure of 90 psia at 16 ft elevation below ground level. How much extra pressure does a pump need to add to ensure a waterline pressure of 30 psia at the top floor 450 ft above ground?

Solution:

The pump exit pressure must balance the top pressure plus the column ΔP. The pump inlet pressure provides part of the absolute pressure.

$$P_{\text{after pump}} = P_{\text{top}} + \Delta P$$

$$\Delta P = \rho g h = 62.2 \text{ lbm/ft}^3 \times 32.174 \text{ ft/s}^2 \times (450 + 16) \text{ ft} \times \frac{1 \text{ lbf s}^2}{32.174 \text{ lbm ft}}$$

$$= 28\,985 \text{ lbf/ft}^2 = 201.3 \text{ lbf/in}^2$$

$$P_{\text{after pump}} = 30 + 201.3 = 231.3 \text{ psia}$$

$$\Delta P_{\text{pump}} = 231.3 - 90 = \mathbf{141.3\ psi}$$

1.83E

As a clothes washer is nealr done it spins 10 lbm of wet clothes with 7 ft/s at a radius of 1 ft. What is the force on the rotating drum? Hint: acceleration in rotation is V^2/r

Solution:

$$F_{centrifugal} = m\,V^2/r = 10 \text{ lbm} \times (7 \text{ ft/s})^2 / 1 \text{ ft}$$
$$= 490 \text{ lbm ft/s}^2 = \mathbf{15.23\ lbf}$$

Temperature

1.84E

The human comfort zone is between 18 and 24°C. What is that range in Fahrenheit?

$$T = 18°C = 32 + 1.8 \times 18 = 64.4 \text{ F}$$
$$T = 24°C = 32 + 1.8 \times 24 = 75.2 \text{ F}$$

So the range is like **64 F to 75 F**.