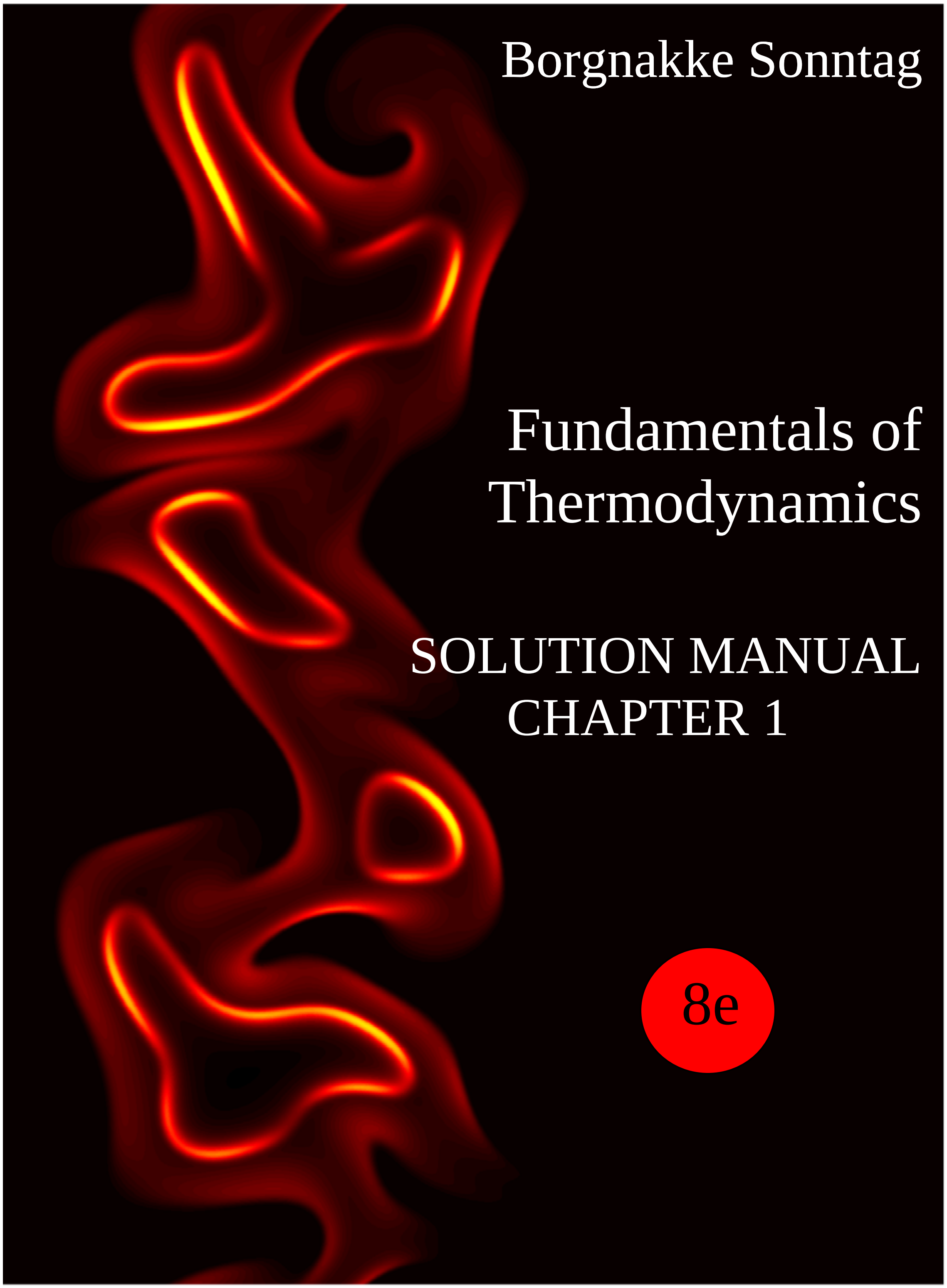


Updated June 2013

CONTENT CHAPTER 1

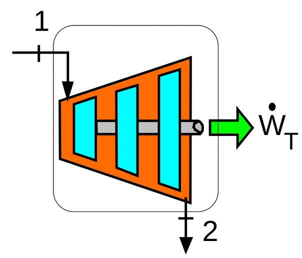
In-Text Concept Questions

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.

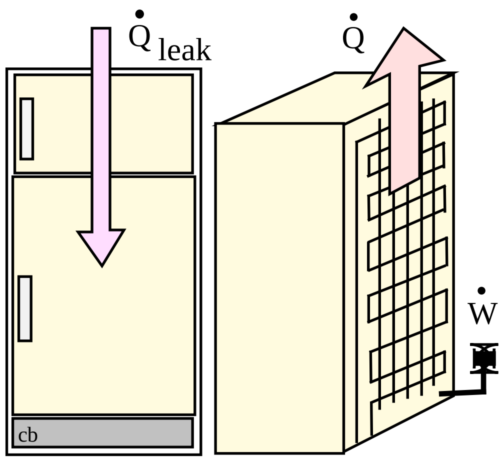


1.b

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 density is higher the displaced volume is smaller for the same force.

1.d

Density of liquid water is $\rho = 1008 - T/2$ [kg/m^3] with T in ^{o}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

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

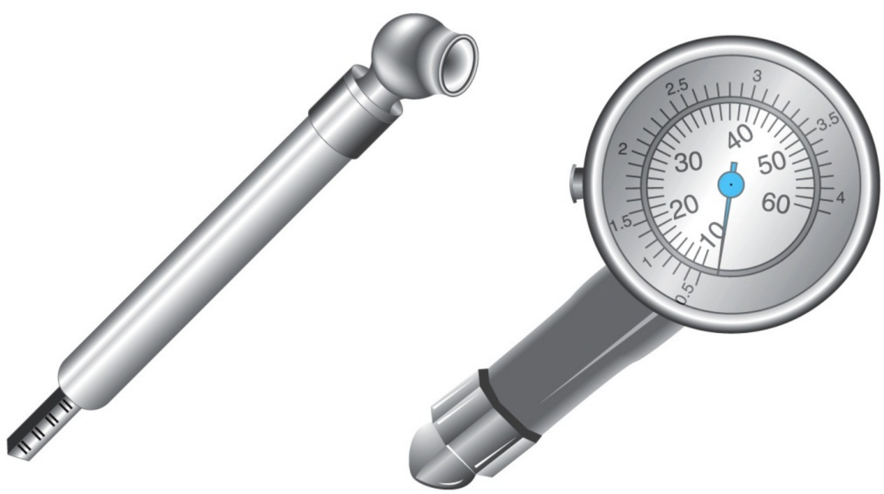


Figure 1.21

1.f

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

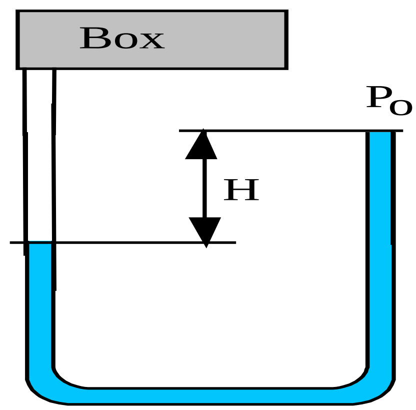
If the fluid density above A is low relative to the manometer fluid then you neglect the pressure variation above position A, say the fluid is a gas like air and the manometer fluid is like liquid water. However, if the fluid above A has a density of the same order of magnitude as the manometer fluid 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.

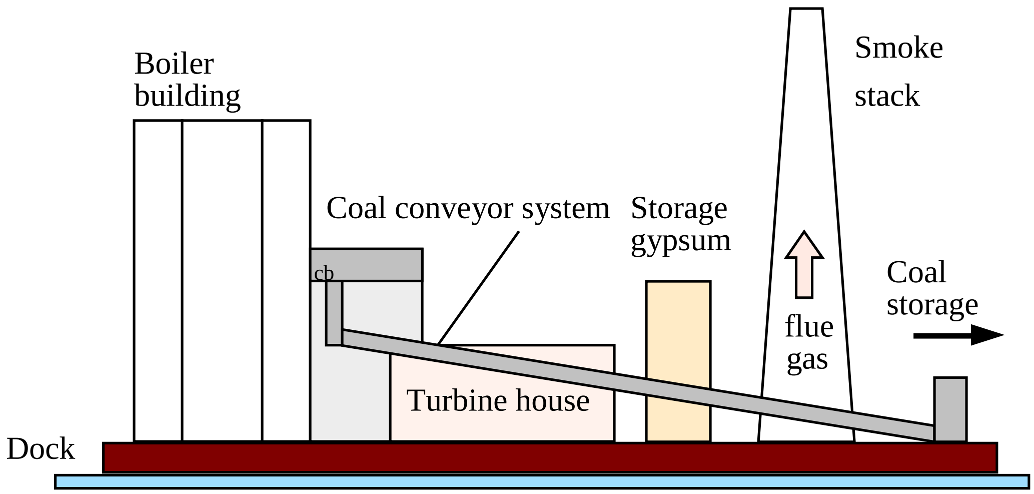


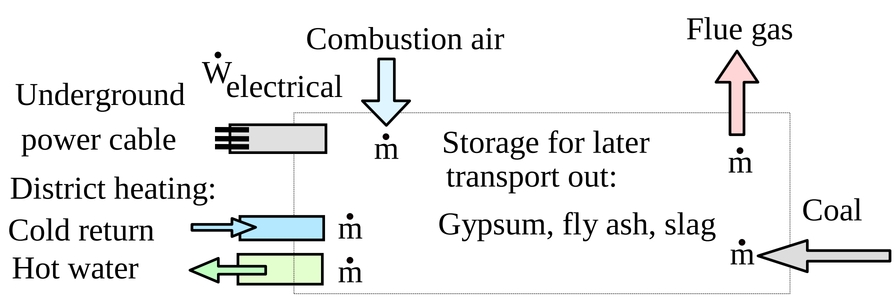
Concept Problems

1.1

Make a control volume around the whole power plant in Fig. 1.1 and with the help of Fig. 1.2 list what flows of mass and energy are in or out and any storage of energy. Make sure you know what is inside and what is outside your chosen C.V.

Solution:

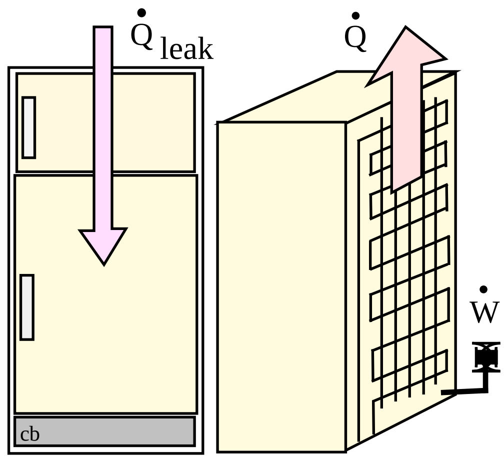




1.2

Make a control volume around the refrigerator in Fig. 1.3. Identify the mass flow of external air and show where you have significant heat transfer and where storage changes.

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.

The storage changes inside the box which is outside of the refrigeration cycle components of Fig. 1.3, when you put some warmer mass inside the refrigerator it is being cooled by the evaporator and the heat is leaving in the condenser.

The condenser warms outside air so the air flow over the condenser line carries away some energy. If natural convection is not enough to do this a small fan is used to blow air in over the condenser (forced convection). Likewise the air being cooled by the evaporator is redistributed inside the refrigerator by a small fan and some ducts.

Since the room is warmer than the inside of the refrigerator heat is transferred into the cold space through the sides and the seal around the door. Also when the door is opened warm air is pulled in and cold air comes out from the refrigerator giving a net energy transfer similar to a heat transfer.

1.3

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.

1.4

A tray of liquid water is placed in a freezer where it cools from 20^{o}C to -5^{o}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^{o}C) and then cooled a little more to -5^{o}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.

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1.5

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 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.

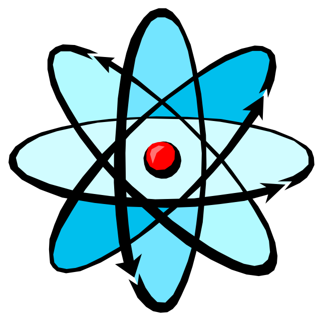
1.6

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.



1.7

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.

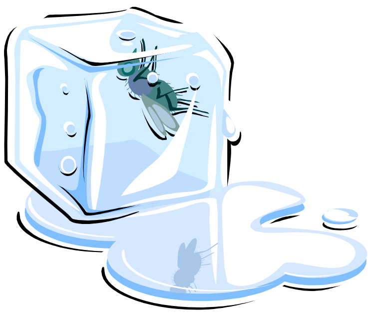
Solution:

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)



Ice cube

Liquid drops falling

Cloud*

* Steam (water vapor) cannot be seen, what you see are tiny drops suspended in air from which we infer that there was some water vapor before it condensed.

1.8

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

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

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

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

1.9

Can you carry 1 m^3 of liquid water?

Solution:

The density of liquid water is about 1000 kg/m^3 from Figure 1.7, see also Table A.3. Therefore the mass in one cubic meter is

$$m = \rho V = 1000 \text{ kg/m}^3 \times 1 \text{ m}^3 = 1000 \text{ kg}$$

and we can not carry that in the standard gravitational field.

1.10

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.

1.11

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:

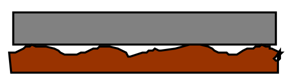
The pressure is force per unit area from page 13:

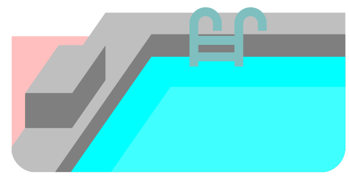
$$P = F/A = mg/A$$

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.

Steel plate
Ground





1.12

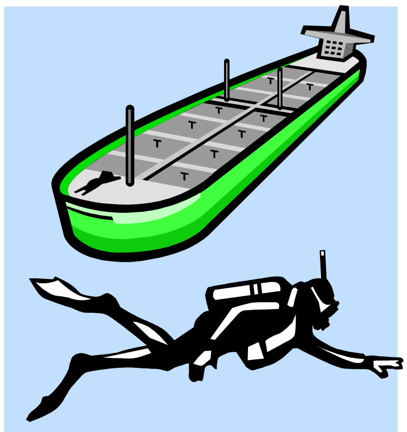
What physically determines the variation of the atmospheric pressure with elevation?

The total mass of the column of air over a unit area and the gravitation gives the force which per unit area is pressure. This is an integral of the density times gravitation over elevation as in Eq.1.4.

To perform the integral the density and gravitation as a function of height (elevation) should be known. Later we will learn that air density is a function of temperature and pressure (and compositions if it varies). Standard curve fits are known that describes this variation and you can find tables with the information about a standard atmosphere. See problems 1.28, 1.64, and 1.95 for some examples.

1.13

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.

1.14

A manometer with water shows a ΔP of $P_o/20$; what is the column height difference?

Solution:

$$\Delta P = P_o/20 = \rho H g$$

$$H = P_o/(20\ \rho\ g) = \frac{101.3 \times 1000\ \text{Pa}}{20 \times 997\ \text{kg/m}^3 \times 9.80665\ \text{m/s}^2}$$

$= \mathbf{0.502\ m}$

1.15

Does the pressure have to be uniform for equilibrium to exist?

No. It depends on what causes a pressure difference. Think about the pressure increasing as you move down into the ocean, the water at different levels are in equilibrium. However if the pressure is different at nearby locations at same elevation in the water or in air that difference induces a motion of the fluid from the higher towards the lower pressure. The motion will persist as long as the pressure difference exist.

1.16

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?

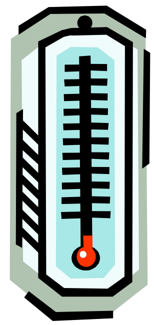
The water pressure right under the ski is not a static pressure but a static plus dynamic pressure that pushes the water away from the ski. The faster you go, the smaller amount of water is displaced, but at a higher velocity.

1.17

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



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

1.18

Convert the formula for water density in In-text Concept Question “d” to be for T in degrees Kelvin.

Solution:

$$\rho = 1008 - T_C/2 \quad [\text{kg/m}^3]$$

We need to express degrees Celsius in degrees Kelvin

$$T_C = T_K - 273.15$$

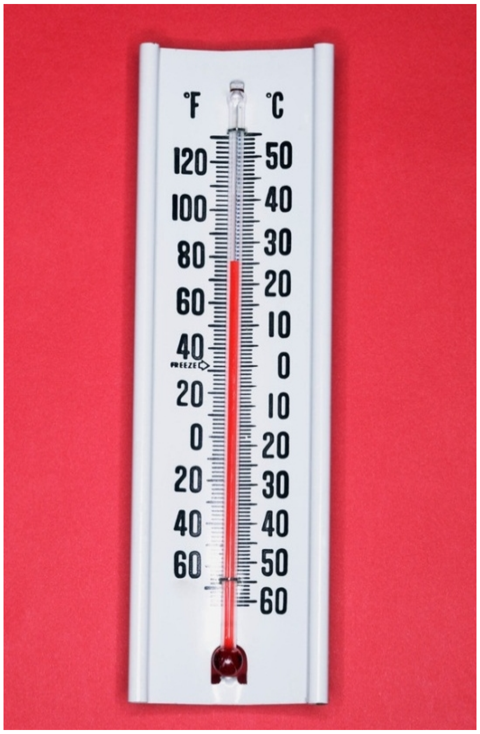
and substitute into formula

$$\rho = 1008 - T_C/2 = 1008 - (T_K - 273.15)/2 = 1144.6 - T_K/2$$

1.19

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

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.



1.20

What is the main difference between the macroscopic kinetic energy in a motion like the blowing of wind versus the microscopic kinetic energy of individual molecules? Which one can you sense with your hand?

Answer:

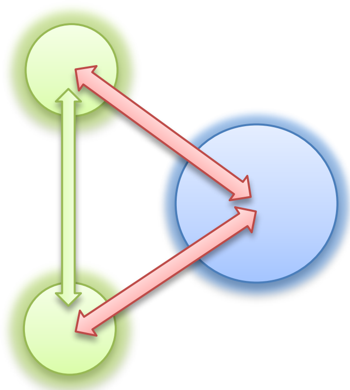
The microscopic kinetic energy of individual molecules is too small for us to sense however when the combined action of billions (actually more like in the order of 1 E19) are added we get to the macroscopic magnitude we can sense. The wind velocity is the magnitude and direction of the averaged velocity over many molecules which we sense. The individual molecules are moving in a random motion (with zero average) on top of this mean (or average) motion. A characteristic velocity of this random motion is the speed of sound, around 340 m/s for atmospheric air and it changes with temperature.

1.21

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

1.22

An apple "weighs" 60 g and has a volume of 75 cm^3 in a refrigerator at 8^oC. What is the apple density? List three intensive and two extensive properties of the apple.

Solution:

$$\rho = \frac{m}{V} = \frac{0.06}{0.000\,075}\ \frac{kg}{m^3} = 800\ \frac{kg}{m^3}$$

Intensive

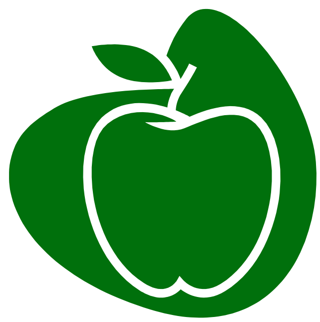
$$\rho = 800\ \frac{kg}{m^3}; \qquad v = \frac{1}{\rho} = 0.001\,25\ \frac{m^3}{kg}$$

$$T = 8°C; \qquad P = 101\ kPa$$

Extensive

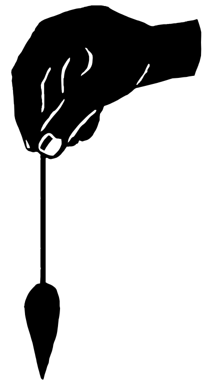
$$m = 60\ g = 0.06\ kg$$

$$V = 75\ cm^3 = 0.075\ L = 0.000\,075\ m^3$$



1.23

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



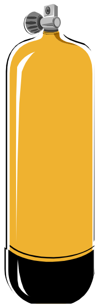
$F = ma = mg$

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

1.24

A stainless steel storage tank contains 5 kg of oxygen gas and 7 kg of nitrogen gas. How many kmoles are in the tank?

Table A.2: $M_{O2} = 31.999$; $M_{N2} = 28.013$



$$n_{O2} = m_{O2} / M_{O2} = \frac{5}{31.999} = 0.15625 \text{ kmol}$$

$$n_{O2} = m_{N2} / M_{N2} = \frac{7}{28.013} = 0.24988 \text{ kmol}$$

$$n_{tot} = n_{O2} + n_{N2} = 0.15625 + 0.24988 = \mathbf{0.40613\ kmol}$$

1.25

A steel cylinder of mass 4 kg contains 4 L of liquid water at 25^{o}C at 100 kPa. Find the total mass and volume of the system. List two extensive and three intensive properties of the water

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 water in Table A.4: $\rho = 997 \text{ kg/m}^3$

Mass of water: $m = \rho V = 997 \text{ kg/m}^3 \times 0.004 \text{ m}^3 = 3.988 \text{ kg}$

Total mass: $m = m_{steel} + m_{water} = 4 + 3.988 =$ **7.988 kg**

Total volume: $V = V_{steel} + V_{water} = 0.000\,512 + 0.004$

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

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

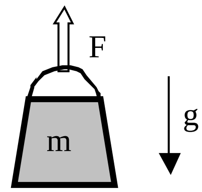
1.26

The "standard" acceleration (at sea level and 45° latitude) due to gravity is 9.80665 m/s^2. What is the force needed to hold a mass of 2 kg at rest in this gravitational field? How much mass can a force of 1 N support?

Solution:

$$ma = 0 = \sum F = F - mg$$

$$F = mg = 2 \text{ kg} \times 9.80665 \text{ m/s}^2 = \mathbf{19.613\ N}$$



$$F = mg \qquad \Rightarrow$$

$$m = \frac{F}{g} = \frac{1 \text{ N}}{9.80665 \text{ m/s}^2} = \mathbf{0.102\ kg}$$

1.27

An aluminum piston of 2.5 kg is in the standard gravitational field where a force of 25 N is applied vertically up. Find the acceleration of the piston.

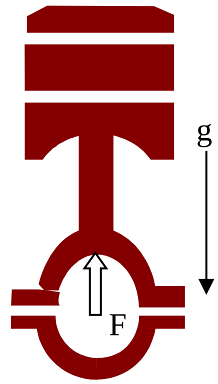
Solution:

$$F_{up} = ma = F - mg$$

$$a = \frac{F - mg}{m} = \frac{F}{m} - g$$

$$= \frac{25\text{ N}}{2.5\text{ kg}} - 9.807\text{ m/s}^2$$

$$= \mathbf{0.193\ ms^{-2}}$$



1.28

When you move up from the surface of the earth the gravitation is reduced as g = $9.807 - 3.32 \times 10^{-6}\, z$, with z as the elevation in meters. How many percent is the weight of an airplane reduced when it cruises at 11 000 m?

Solution:

$g_o = 9.807 \text{ ms}^{-2}$

$g_H = 9.807 - 3.32 \times 10^{-6} \times 11\,000 = 9.7705 \text{ ms}^{-2}$

$W_o = m\, g_o \;\; ; \;\; W_H = m\, g_H$

$$W_H / W_o = g_H / g_o = \frac{9.7705}{9.807} = 0.9963$$

Reduction = 1 – 0.9963 = 0.0037 or **0.37%**

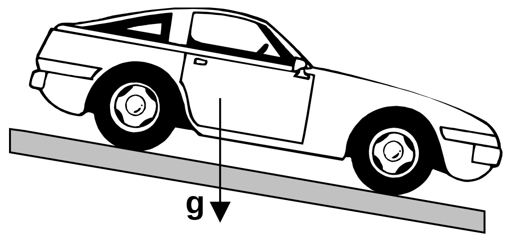
i.e. we can neglect that for most applications.

1.29

A car rolls down a hill with a slope so the gravitational “pull” in the direction of motion is one tenth of the standard gravitational force (see Problem 1.26). If the car has a mass of 2500 kg find the acceleration.

Solution:

$$ma = \sum F = mg / 10$$
$$a = mg / 10m = g/10$$
$$= 9.80665 \text{ (m/s}^2\text{)} / 10$$
$$= \mathbf{0.981 \ m/s^2}$$



This acceleration does not depend on the mass of the car.

1.30

A van is driven at 60 km/h and is brought to a full stop with constant deceleration in 5 seconds. If the total car and driver mass is 2075 kg find the necessary force.

Solution:

Acceleration is the time rate of change of velocity.

$$a = \frac{d\mathbf{V}}{dt} = \frac{60 \times 1000}{3600 \times 5} = 3.333 \text{ m/s}^2$$

$ma = \sum F$;

$F_{net} = ma = 2075 \text{ kg} \times 3.333 \text{ m/s}^2 = \mathbf{6916\ N}$

1.31

A 1500-kg car moving at 20 km/h is accelerated at a constant rate of 4 m/s^2 up to a speed of 75 km/h. What are the force and total time required?

Solution:

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

$$\Delta t = \frac{\Delta\mathbf{V}}{a} = \frac{(75 - 20) \text{ km/h} \times 1000 \text{ m/km}}{3600 \text{ s/h} \times 4 \text{ m/s}^2} = \mathbf{3.82 \text{ sec}}$$

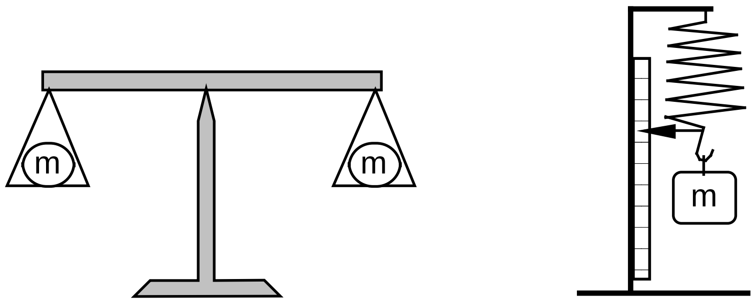
$$F = ma = 1500 \text{ kg} \times 4 \text{ m/s}^2 = \mathbf{6000 \text{ N}}$$

1.32

On the moon the gravitational acceleration is approximately one-sixth that on the surface of the earth. A 5-kg mass is “weighed” with a beam balance on the surface on the moon. What is the expected reading? If this mass is weighed with a spring scale that reads correctly for standard gravity on earth (see Problem 1.26), what is the reading?

Solution:

Moon gravitation is: $g = g_{earth}/6$



Beam Balance Reading is **5 kg**
This is mass comparison

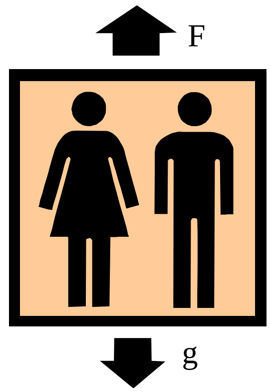
Spring Balance Reading is in kg units
Force comparison length $\propto$ F $\propto$ g

Reading will be $\mathbf{\frac{5}{6}}$ **kg**

1.33

The elevator in a hotel has a mass of 750 kg, and it carries six people with a total mass of 450 kg. How much force should the cable pull up with to have an acceleration of 1 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.

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

$$F = ma + mg = m(a + g)$$
$$= (750 + 450)\ \text{kg} \times (1 + 9.81)\ \text{m/s}^2$$
$$= \mathbf{12\ 972\ N}$$

1.34

One of the people in the previous problem weighs 80 kg standing still. 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

$$\begin{aligned} F &= ma + mg = m(a + g) \\ &= 80 \text{ kg} \times (1 + 9.81) \text{ m/s}^2 \\ &= 864.8 \text{ N} \\ &= x \text{ kg} \times 9.81 \text{ m/s}^2 \end{aligned}$$

Solve for x

$$x = 864.8 \text{ N}/ 9.81 \text{ m/s}^2 = \mathbf{88.15\ kg}$$

The person then feels like having a mass of 88 kg instead of 80 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 88 kp instead of the normal 80 kp.

1.35

A bottle of 12 kg steel has 1.75 kmole of liquid propane. It accelerates horizontal with 3 m/s^2, what is the needed force?

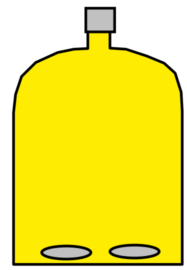
Solution:

The molecular weight for propane is $M = 44.094$ from Table A.2. The force must accelerate both the container mass and the propane mass.

$$m = m_{steel} + m_{propane} = 12 + (1.75 \times 44.094) = 90.645 \text{ kg}$$

$$ma = \sum F \quad \Rightarrow$$

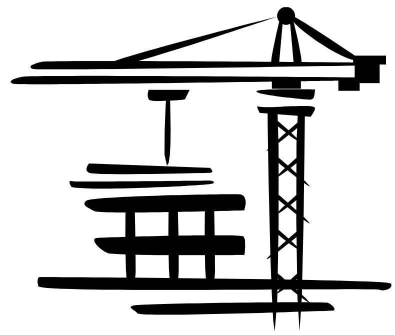
$$F = ma = 90.645 \text{ kg} \times 3 \text{ m/s}^2 = \mathbf{271.9\ N}$$



1.36

Some steel beams with a total mass of 700 kg are raised by a crane with an acceleration of 2 m/s^2 relative to the ground at a location where the local gravitational acceleration is 9.5 m/s^2. Find the required force.

Solution:



$F = ma = F_{up} - mg$

$F_{up} = ma + mg = 700 \text{ kg} (2 + 9.5)$ m/s^2

$= \mathbf{80\ 500\ N}$

Specific Volume

1.37

A 1 m^3 container is filled with 400 kg of granite stone, 200 kg dry sand and 0.2 m^3 of liquid 25°C water. Use properties from tables A.3 and A.4. Find the average specific volume and density of the masses when you exclude air mass and volume.

Solution:

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

$$m_{liq} = V_{liq}/v_{liq} = V_{liq}\,\rho_{liq} = 0.2\ m^3 \times 997\ kg/m^3 = 199.4\ kg$$

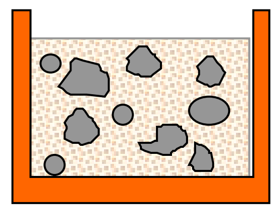
$$m_{TOT} = m_{stone} + m_{sand} + m_{liq} = 400 + 200 + 199.4 = 799.4\ kg$$

$$V_{stone} = mv = m/\rho = 400\ kg/\ 2750\ kg/m^3 = 0.1455\ m^3$$

$$V_{sand} = mv = m/\rho = 200/\ 1500 = 0.1333\ m^3$$

$$V_{TOT} = V_{stone} + V_{sand} + V_{liq}$$

$$= 0.1455 + 0.1333 + 0.2 = 0.4788\ m^3$$



$$v = V_{TOT} / m_{TOT} = 0.4788/799.4 = \mathbf{0.000599\ m^3/kg}$$

$$\rho = 1/v = m_{TOT}/V_{TOT} = 799.4/0.4788 = \mathbf{1669.6\ kg/m^3}$$

1.38

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:

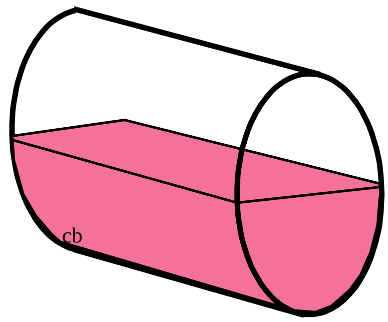
$$m = \rho V = 110 \text{ kg/m}^3 \times 100\,000 \text{ m}^3 = 11 \times 10^{6} \text{ kg}$$

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.

1.39

A 15-kg steel gas tank holds 300 L of liquid gasoline, having a density of 800 kg/m^3. If the system is decelerated with 2g what is the needed force?

Solution:



$m = m_{tank} + m_{gasoline}$

$= 15 \text{ kg} + 0.3 \text{ m}^3 \times 800 \text{ kg/m}^3$

$= 255 \text{ kg}$

$F = ma = 255 \text{ kg} \times 2 \times 9.81 \text{ m/s}^2$

$=$ **5003 N**

1.40

A 5 m^3 container is filled with 900 kg of granite (density 2400 kg/m^3) and the rest of the volume is air with density 1.15 kg/m^3. Find the mass of air and the overall (average) specific volume.

Solution:

$$m_{air} = \rho\ V = \rho_{air}\ (\ V_{tot} - \frac{m_{granite}}{\rho}\ )$$

$$= 1.15\ [\ 5 - \frac{900}{2400}\ ] = 1.15\ \times 4.625 = \mathbf{5.32\ kg}$$

$$v = \frac{V}{m} = \frac{5}{900 + 5.32} = \mathbf{0.005\ 52\ m^3/kg}$$

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.

1.41

A tank has two rooms separated by a membrane. Room A has 1 kg air and volume 0.5 m^3, room B has 0.75 m^3 air with density 0.8 kg/m^3. The membrane is broken and the air comes to a uniform state. Find the final density of the air.

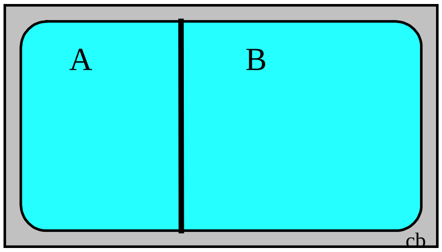
Solution:

Density is mass per unit volume

$$m = m_A + m_B = m_A + \rho_B V_B = 1 + 0.8 \times 0.75 = 1.6 \text{ kg}$$

$$V = V_A + V_B = 0.5 + 0.75 = 1.25 \text{ m}^3$$

$$\rho = \frac{m}{V} = \frac{1.6}{1.25} \frac{\text{kg}}{\text{m}^3} = \mathbf{1.28\ kg/m^3}$$



1.42

One kilogram of diatomic oxygen (O_2 molecular weight 32) is contained in a 500-L tank. Find the specific volume on both a mass and mole basis (v and $\bar{v}$).

Solution:

From the definition of the specific volume

$$v = \frac{V}{m} = \frac{0.5}{1} \frac{m^3}{kg} = \mathbf{0.5\ m^3/kg}$$

$$\bar{v} = \frac{V}{n} = \frac{V}{m/M} = M\,v = 32\ \text{kg/kmol} \times 0.5\ \text{m}^3\text{/kg} = \mathbf{16\ m^3/kmol}$$

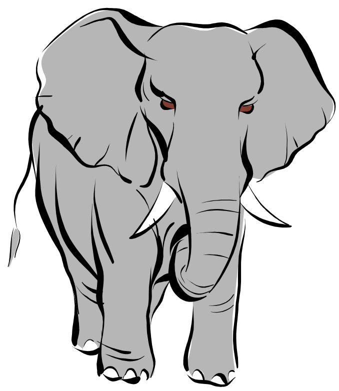
Pressure

1.43

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: $ma = 0 = PA – mg$

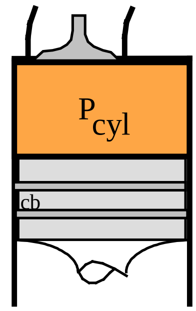
$$P = mg/A = 5000 \text{ kg} \times 9.81 \text{ m/s}^2 /(4 \times 0.02 \text{ m}^2)$$
$$= 613\,125 \text{ Pa} = \mathbf{613\ kPa}$$



1.44

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?

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



1.45

The hydraulic lift in an auto-repair shop has a cylinder diameter of 0.2 m. To what pressure should the hydraulic fluid be pumped to lift 40 kg of piston/arms and 700 kg of a car?

Solution:

Force acting on the mass by the gravitational field

$$F\downarrow = ma = mg = 740 \times 9.80665 = 7256.9 \text{ N} = 7.257 \text{ kN}$$

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

$$A = \pi D^2 (1 / 4) = 0.031416 \text{ m}^2$$

$$P = 101 \text{ kPa} + \frac{7.257 \text{ kN}}{0.031416 \text{ m}^2} = \mathbf{332\ kPa}$$

1.46

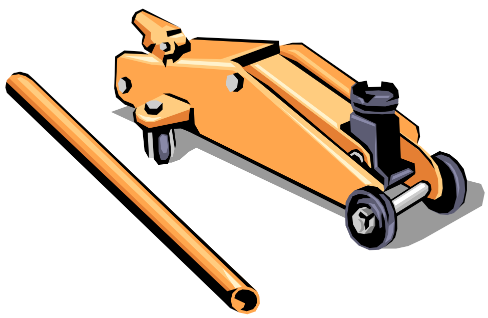
A hydraulic lift has a maximum fluid pressure of 500 kPa. What should the piston-cylinder diameter be so it can lift a mass of 850 kg?

Solution:

With the piston at rest the static force balance is

$$F\uparrow = P\ A = F\downarrow = mg$$
$$A = \pi\ r^2 = \pi\ D^2/4$$
$$PA = P\ \pi\ D^2/4 = mg \quad \Rightarrow \quad D^2 = \frac{4mg}{P\ \pi}$$

$$D = 2\sqrt{\frac{mg}{P\pi}} = 2\sqrt{\frac{850\text{ kg} \times 9.807\text{ m/s}^2}{500\text{ kPa} \times \pi \times 1000\text{ (Pa/kPa)}}} = \mathbf{0.146\ m}$$



1.47

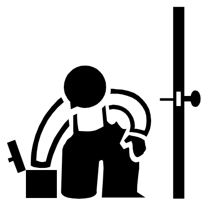
A laboratory room keeps a vacuum of 0.1 kPa. What net force does that put on the door of size 2 m by 1 m?

Solution:

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

$$F = P_{outside}\ A - P_{inside}\ A = \Delta P\ A = 0.1\ \text{kPa} \times 2\ \text{m} \times 1\ \text{m} = \mathbf{200\ N}$$

Remember that kPa is kN/m^2.



1.48

A vertical hydraulic cylinder has a 125-mm diameter piston with hydraulic fluid inside the cylinder and an ambient pressure of 1 bar. Assuming standard gravity, find the piston mass that will create a pressure inside of 1500 kPa.

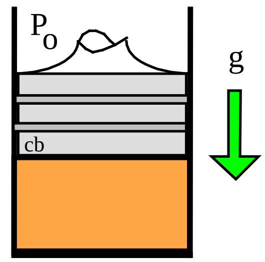
Solution:

Force balance:

$$F\uparrow = PA = F\downarrow = P_0A + m_pg;$$

$$P_0 = 1 \text{ bar} = 100 \text{ kPa}$$

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



$$m_p = (P - P_0)\,\frac{A}{g} = (\ 1500 - 100\ )\ \text{kPa} \times 1000\ \text{Pa/kPa} \times \frac{0.01227}{9.80665}\,\frac{\text{m}^2}{\text{m/s}^2}$$

$$= \mathbf{1752\ kg}$$

1.49

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: $ma = 0 = PA - mg$

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

1.50

A piston/cylinder with cross sectional area of 0.01 m^2 has a piston mass of 100 kg resting on the stops, as shown in Fig. P1.50. With an outside atmospheric pressure of 100 kPa, what should the water pressure be to lift the piston?

Solution:

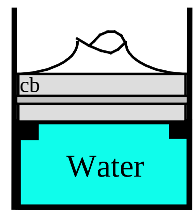
The force acting down on the piston comes from gravitation and the outside atmospheric pressure acting over the top surface.

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

Now solve for P (divide by 1000 to convert to kPa for 2nd term)

$$P = P_0 + \frac{m_p g}{A} = 100 \text{ kPa} + \frac{100 \times 9.80665}{0.01 \times 1000} \text{ kPa}$$

$$= 100 \text{ kPa} + 98.07 \text{ kPa} = \mathbf{198\ kPa}$$



1.51

A large exhaust fan in a laboratory room keeps the pressure inside at 10 cm water vacuum relative to the hallway. What is the net force on the door measuring 1.9 m by 1.1 m?

Solution:

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

$$
\begin{aligned}
F &= P_{outside}\, A - P_{inside}\, A = \Delta P \times A \\
&= 10 \text{ cm } H_2O \times 1.9 \text{ m} \times 1.1 \text{ m} \\
&= 0.10 \times 9.80638 \text{ kPa} \times 2.09 \text{ m}^2 \\
&= \mathbf{2049\ N}
\end{aligned}
$$

Table A.1: 1 m H_2O is 9.80638 kPa and kPa is kN/m^2.

1.52

A tornado rips off a 100 m^2 roof with a mass of 1000 kg. What is the minimum vacuum pressure needed to do that if we neglect the anchoring forces?

Solution:

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

$$F = P_{inside}\, A - P_{outside} A = \Delta P\ A$$

That force must overcome the gravitation mg, so the balance is

$$\Delta P\ A = mg$$

$$\Delta P = mg/A = (1000 \text{ kg} \times 9.807 \text{ m/s}^2)/100 \text{ m}^2 = \mathbf{98\ Pa = 0.098\ kPa}$$

Remember that kPa is kN/m^2.

1.53

A 5-kg cannon-ball acts as a piston in a cylinder with a diameter of 0.15 m. As the gun-powder is burned a pressure of 7 MPa is created in the gas behind the ball. What is the acceleration of the ball if the cylinder (cannon) is pointing horizontally?

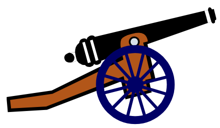
Solution:

The cannon ball has 101 kPa on the side facing the atmosphere.

$$ma = F = P_1 \times A - P_0 \times A = (P_1 - P_0) \times A$$

$$= (7000 - 101) \text{ kPa} \times \pi \, (0.15^2 /4) \text{ m}^2 = 121.9 \text{ kN}$$

$$a = \frac{F}{m} = \frac{121.9 \text{ kN}}{5 \text{ kg}} = \mathbf{24\,380\ m/s^2}$$



1.54

Repeat the previous problem for a cylinder (cannon) pointing 40 degrees up relative to the horizontal direction.

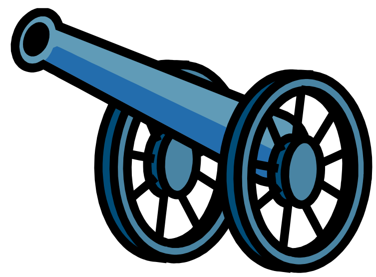
Solution:

$$ma = F = (P_1 - P_0) A - mg \sin 40^0$$

$$ma = (7000 - 101) \text{ kPa} \times \pi \times (0.15^2 / 4) \text{ m}^2 - 5 \times 9.807 \times 0.6428 \text{ N}$$

$$= 121.9 \text{ kN} - 31.52 \text{ N} = 121.87 \text{ kN}$$

$$a = \frac{F}{m} = \frac{121.87 \text{ kN}}{5 \text{ kg}} = \mathbf{24\ 374\ m/s^2}$$

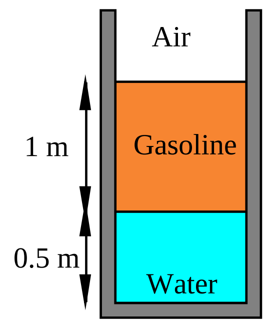


1.55

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 water on top of which is a 1 m high layer of gasoline. This is shown in Fig. P1.55. The gasoline surface is exposed to atmospheric air at 101 kPa. What is the highest pressure in the water?

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

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

The densities from Table A.4 are:

$$\rho_{gasoline} = 750\ kg/m^3; \quad \rho_{water} = 997\ kg/m^3$$

$$P = 101\ kPa + [750 \times 1 + 997 \times 0.5]\ kg/m^2 \times \frac{9.807}{1000}\ (m/s^2)\ (kPa/Pa)$$

$$= \mathbf{113.2\ kPa}$$

1.56

An underwater buoy is anchored at the seabed with a cable, and it contains a total mass of 250 kg. What should the volume be so that the cable holds it down with a force of 1000 N?

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

$$ma = 0 = m_{H2O}g - mg - F$$
$$= \rho_{H2O}Vg - mg - F$$
$$V = (mg + F)/\ \rho_{H2O}g = (m + F/g)/\ \rho_{H2O}$$
$$= (250\ \text{kg} + 1000\ \text{N}/9.81\ \text{m/s}^2)\ /\ 997\ \text{kg/m}^3$$
$$= \mathbf{0.353\ m^3}$$

1.57

At the beach, atmospheric pressure is 1025 mbar. You dive 15 m down in the ocean and you later climb a hill up to 250 m elevation. Assume the density of water is about 1000 kg/m^3 and the density of air is 1.18 kg/m^3. What pressure do you feel at each place?

Solution:

$\Delta P = \rho g h$,

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

$$P_{ocean} = P_0 + \Delta P = 1025 \times 100 \text{ Pa} + 1000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 15 \text{ m}$$

$$= 2.4965 \times 10^5 \text{ Pa} = \mathbf{250\ kPa}$$

$$P_{hill} = P_0 - \Delta P = 1025 \times 100 \text{ Pa} - 1.18 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 250 \text{ m}$$

$$= 0.99606 \times 10^5 \text{ Pa} = \mathbf{99.61\ kPa}$$

1.58

What is the pressure at the bottom of a 5 m tall column of fluid with atmospheric pressure 101 kPa on the top surface if the fluid is

a) water at 20°C b) glycerine 25°C or c) gasoline 25°C

Solution:

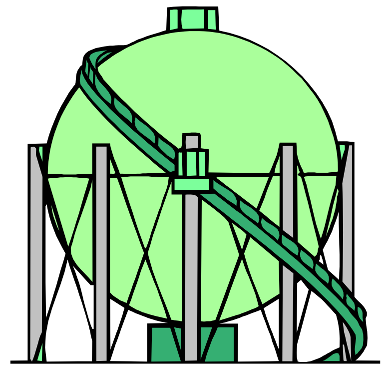
Table A.4: ρ_{H2O} = 997 kg/m^3; ρ_{Glyc} = 1260 kg/m^3; $\rho_{gasoline}$ = 750 kg/m^3

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

a) $\Delta P = \rho g h = 997 \times 9.807 \times 5 = 48\,888$ Pa
$P = 101 + 48.99 =$ **149.9 kPa**

b) $\Delta P = \rho g h = 1260 \times 9.807 \times 5 = 61\,784$ Pa
$P = 101 + 61.8 =$ **162.8 kPa**

c) $\Delta P = \rho g h = 750 \times 9.807 \times 5 = 36\,776$ Pa
$P = 101 + 36.8 =$ **137.8 kPa**

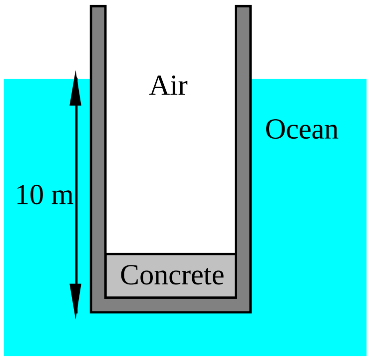


1.59

A steel tank of cross sectional area 3 m^2 and 16 m tall weighs 10 000 kg and it is open at the top, as shown in Fig. P1.59. 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.



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

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

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

$$m_{concrete} = (\rho_{ocean}hA - m_{tank}) = 997 \times 10 \times 3 - 10\,000 = \mathbf{19\,910\ kg}$$

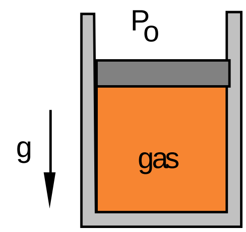
Notice: The first term is the mass of the displaced ocean water. The force up is the weight (mg) of this mass called buoyancy which balances with gravitation and the force from P_0 cancel.

1.60

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



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

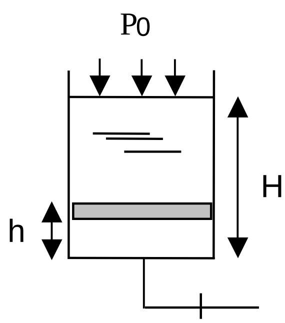
$$= 101.325 + \frac{5 \times 25}{1000 \times 0.0015} \; \frac{\text{kPa kg m/s}^2}{\text{Pa m}^2}$$

$= \mathbf{184.7\ kPa}$

1.61

Liquid water with density ρ is filled on top of a thin piston in a cylinder with cross-sectional area *A* and total height *H*, as shown in Fig. P1.61. Air is let in under the piston so it pushes up, spilling the water over the edge. Derive the formula for the air pressure as a function of piston elevation from the bottom, *h*.

Solution:



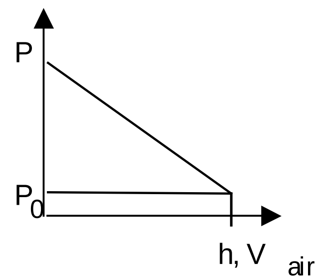
Force balance

Piston: $F\uparrow = F\downarrow$

$PA = P_0A + m_{H_2O}g$

$P = P_0 + m_{H_2O}g/A$

$$\mathbf{P = P_0 + (H - h)\rho g}$$



Manometers and Barometers

1.62

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.

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

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

1.63

The density of atmospheric air is about 1.15 kg/m^3, which we assume is constant. How large an absolute pressure will a pilot see when flying 2000 m above ground level where the pressure is 101 kPa.

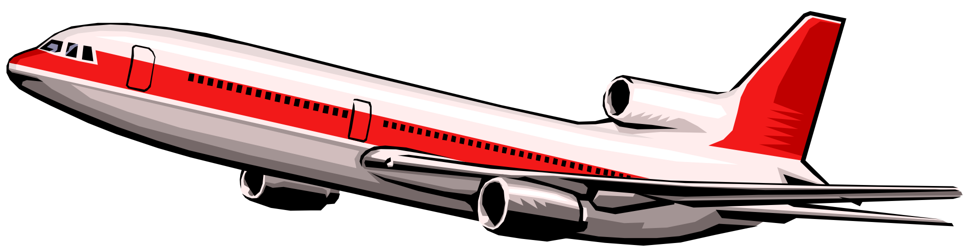
Solution:

Assume g and ρ are constant then the pressure difference to carry a column of height 2000 m is from Fig.2.10

$$\Delta P = \rho g h = 1.15\ kg/m^3 \times 9.807\ ms^{-2} \times 2000\ m$$
$$= 22\ 556\ Pa = 22.6\ kPa$$

The pressure on top of the column of air is then

$$P = P_0 - \Delta P = 101 - 22.6 = \mathbf{78.4\ kPa}$$



1.64

The standard pressure in the atmosphere with elevation (H) above sea level can be correlated as $P = P_0 (1 - H/L)^{5.26}$ with L = 44 300 m. With the local sea level pressure P_0 at 101 kPa, what is the pressure at 10 000 m elevation?

$$P = P_0 (1 - H/L)^{5.26}$$

$$= 101 \text{ kPa} (1 - 10\,000/44\,300)^{5.26}$$

$$= \mathbf{26.3\ kPa}$$

1.65

A barometer to measure absolute pressure shows a mercury column height of 725 mm. The temperature is such that the density of the mercury is 13 550 kg/m^3. Find the ambient pressure.

Solution:

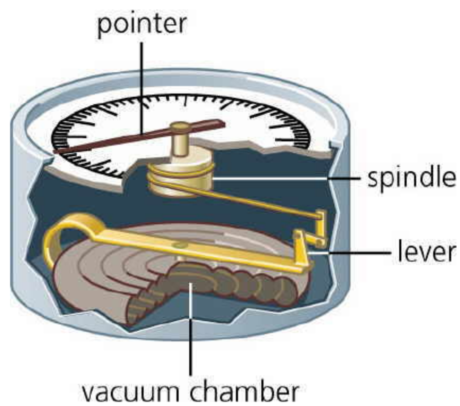
Hg : $L = 725$ mm $= 0.725$ m; $\rho = 13\ 550$ kg/m^3

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

$$P = \rho L g = 13\ 550 \text{ kg/m}^3 \times 9.80665 \text{ m/s}^2 \times 0.725 \text{ m} \times 10^{-3} \text{ kPa/Pa}$$

$$= \mathbf{96.34\ kPa}$$

This is a more common type that does not involve mercury as an older wall mounted unit.



1.66

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:

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**

1.67

A manometer shows a pressure difference of 1 m of liquid mercury. Find ΔP in kPa.

Solution:

Hg : $L = 1$ m; $\rho = 13\,580$ kg/m^3 from Table A.4 (or read Fig 1.8)

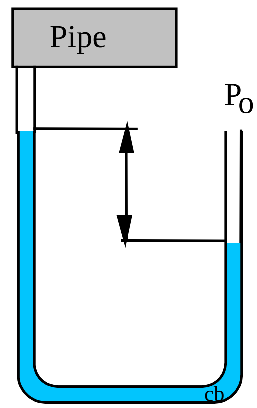
The pressure difference ΔP balances the column of height L so from Eq.1.2

$$\Delta P = \rho\, g\, L = 13\,580 \text{ kg/m}^3 \times 9.80665 \text{ m/s}^2 \times 1.0 \text{ m} \times 10^{-3} \text{ kPa/Pa}$$
$$= \mathbf{133.2\ kPa}$$

1.68

Blue manometer fluid of density 925 kg/m^3 shows a column height difference of 3 cm vacuum with one end attached to a pipe and the other open to P_0 = 101 kPa. What is the absolute pressure in the pipe?

Solution:



Since the manometer shows a vacuum we have

$$P_{PIPE} = P_0 - \Delta P$$

$$\Delta P = \rho g h = 925 \text{ kg/m}^3 \times 9.807 \text{ m/s}^2 \times 0.03 \text{ m}$$

$$= 272.1 \text{ Pa} = 0.272 \text{ kPa}$$

$$P_{PIPE} = 101 - 0.272 = \mathbf{100.73 \text{ kPa}}$$

1.69

What pressure difference does a 10 m column of atmospheric air show?

Solution:

The pressure difference for a column is from Eq.1.2

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

So we need density of air from Fig. 2.8 or Table A.5, $\rho = 1.2\ kg/m^3$

$$\Delta P = 1.2\ kg/m^3 \times 9.81\ ms^{-2} \times 10\ m = 117.7\ Pa = \mathbf{0.12\ kPa}$$

1.70

A barometer measures 760 mmHg at street level and 735 mmHg on top of a building. How tall is the building if we assume air density of 1.15 kg/m^3?

Solution:

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

$$H = \Delta P/\rho g = \frac{760 - 735}{1.15 \times 9.807} \frac{\text{mmHg}}{\text{kg/m}^2\text{s}^2} \frac{133.32 \text{ Pa}}{\text{mmHg}} = \mathbf{295\ m}$$

1.71

The pressure gauge on an air tank shows 75 kPa when the diver is 10 m down in the ocean. At what depth will the gauge pressure be zero? What does that mean?

Ocean H_20 pressure at 10 m depth is

$$P_{water} = P_0 + \rho L g = 101.3 + \frac{997 \times 10 \times 9.80665}{1000} = 199 \text{ kPa}$$

Air Pressure (absolute) in tank

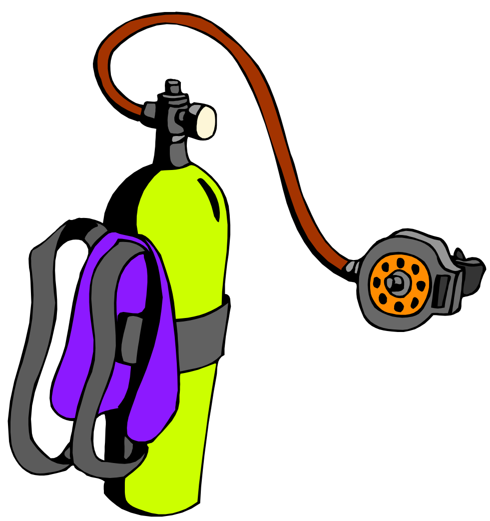
$$P_{tank} = 199 + 75 = 274 \text{ kPa}$$

Tank Pressure (gauge) reads zero at H_20 local pressure

$$274 = 101.3 + \frac{997 \times 9.80665}{1000} L$$

$$L = \mathbf{17.66\ m}$$

At this depth you will have to suck the air in, it can no longer push itself through a valve.



1.72

An exploration submarine should be able to go 1200 m down in the ocean. If the ocean density is 1020 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

$$\Delta P = \rho L g = (1020 \text{ kg/m}^3 \times 1200 \text{ m} \times 9.807 \text{ m/s}^2) / (1000 \text{ Pa/kPa})$$
$$= 12\ 007 \text{ kPa} \approx \mathbf{12\ MPa}$$

1.73

A submarine maintains 101 kPa inside it and it dives 240 m down in the ocean having an average density of 1030 kg/m^3. What is the pressure difference between the inside and the outside of the submarine hull?

Solution:

Assume the atmosphere over the ocean is at 101 kPa, then ΔP is from the 240 m column water.

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

$$= (1030 \text{ kg/m}^3 \times 240 \text{ m} \times 9.807 \text{ m/s}^2) / 1000 = \mathbf{2424 \text{ kPa}}$$

1.74

Assume we use a pressure gauge to measure the air pressure at street level and at the roof of a tall building. If the pressure difference can be determined with an accuracy of 1 mbar (0.001 bar) what uncertainty in the height estimate does that corresponds to?

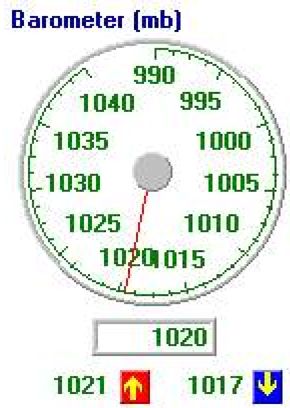
Solution:

$\rho_{air} = 1.169\ kg/m^3$ from Table A.5

$\Delta P = 0.001\ bar = 100\ Pa$

$$L = \frac{\Delta P}{\rho g} = \frac{100}{1.169 \times 9.807} = \mathbf{8.72\ m}$$

As you can see that is not really accurate enough for many purposes.



1.75

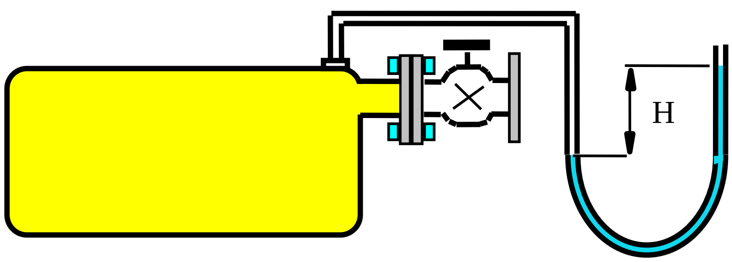
The absolute pressure in a tank is 115 kPa and the local ambient absolute pressure is 97 kPa. If a U-tube with mercury, density 13550 kg/m^3, is attached to the tank to measure the gage pressure, what column height difference would it show?

Solution:

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

$H = (P_{tank} - P_0)/\rho g = [(115 - 97) \times 1000]\ \text{Pa} / (13550\ \text{kg/m}^3 \times 9.81\ \text{m/s}^2)$

$= \mathbf{0.135\ m = 13.5\ cm}$



1.76

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?

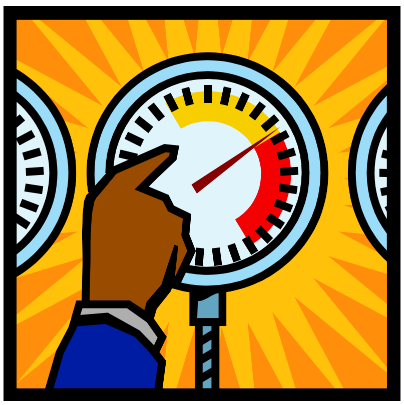
Solution:

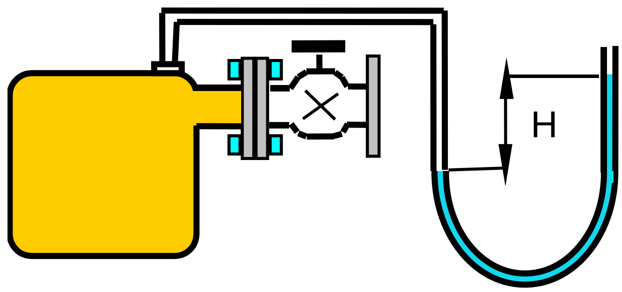
Since the manometer shows a pressure difference we have

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

$$L = \Delta P / \rho g = \frac{(135 - 101)\ \text{kPa}}{997\ \text{kg m}^{-3} \times 10 \times 9.807\ \text{m/s}^2} \frac{1000\ \text{Pa}}{\text{kPa}}$$

$$= \mathbf{3.467\ m}$$



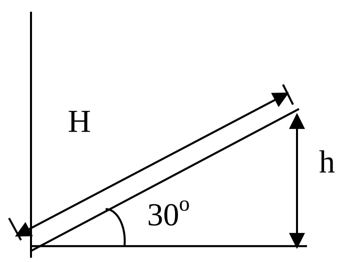


1.77

A U-tube manometer filled with water, density 1000 kg/m^3, shows a height difference of 25 cm. What is the gauge pressure? If the right branch is tilted to make an angle of 30° with the horizontal, as shown in Fig. P1.77, what should the length of the column in the tilted tube be relative to the U-tube?

Solution:

Same height in the two sides in the direction of g.



$$\Delta P = F/A = mg/A = V\rho g/A = h\rho g$$
$$= 0.25 \text{ m} \times 1000 \text{ kg/m}^3 \times 9.807 \text{m/s}^2$$
$$= 2452.5 \text{ Pa}$$
$$= \mathbf{2.45\ kPa}$$

$$h = H \times \sin 30°$$
$$\Rightarrow H = h/\sin 30° = 2h = \mathbf{50\ cm}$$

1.78

A pipe flowing light oil has a manometer attached as shown in Fig. P1.78. What is the absolute pressure in the pipe flow?

Solution:

Table A.3: $\rho_{oil} = 910 \text{ kg/m}^3$; $\rho_{water} = 997 \text{ kg/m}^3$

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

$$P_{PIPE} = P_{BOT} - \rho_{water}\, g\, H_1 - \rho_{oil}\, g\, H_2$$
$$= P_{BOT} - 997 \times 9.807 \times 0.1 - 910 \times 9.807 \times 0.2$$
$$= P_{BOT} - 977.7 \text{ Pa} - 1784.9 \text{ Pa}$$

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

1.79

The difference in height between the columns of a manometer is 200 mm with a fluid of density 900 kg/m^3. What is the pressure difference? What is the height difference if the same pressure difference is measured using mercury, density 13600 kg/ m^3, as manometer fluid?

Solution:

$$\Delta P = \rho_1 g h_1 = 900 \text{ kg/m}^3 \times 9.807 \text{ m/s}^2 \times 0.2 \text{ m} = 1765.26 \text{ Pa} = \mathbf{1.77\ kPa}$$

$$h_{Hg} = \Delta P / (\rho_{hg}\ g) = (\rho_1\ g h_1) / (\rho_{hg}\ g) = \frac{900}{13600} \times 0.2 \text{ m}$$

$$= \mathbf{0.0132\ m = 13.2\ mm}$$

1.80

Two cylinders are filled with liquid water, $\rho = 1000\ kg/m^3$, and connected by a line with a closed valve, as shown in Fig. P1.80. A has 100 kg and B has 500 kg of water, their cross-sectional areas are $A_A = 0.1\ m^2$ and $A_B = 0.25\ m^2$ and the height h is 1 m. Find the pressure on each side of the valve. The valve is opened and water flows to an equilibrium. Find the final pressure at the valve location.

Solution:

$$V_A = v_{H_2O} m_A = m_A/\rho = 0.1 = A_A h_A \quad \Rightarrow \quad h_A = 1\ m$$

$$V_B = v_{H_2O} m_B = m_B/\rho = 0.5 = A_B h_B \quad \Rightarrow \quad h_B = 2\ m$$

$$P_{VB} = P_0 + \rho g(h_B + H) = 101325 + 1000 \times 9.81 \times 3 = 130\ 755\ Pa$$

$$P_{VA} = P_0 + \rho g h_A = 101325 + 1000 \times 9.81 \times 1 = 111\ 135\ Pa$$

Equilibrium: same height over valve in both

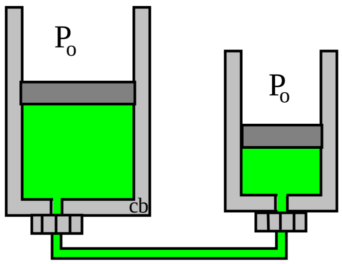
$$V_{tot} = V_A + V_B = h_2 A_A + (h_2 - H)A_B \Rightarrow h_2 = \frac{h_A A_A + (h_B + H)A_B}{A_A + A_B} = 2.43\ m$$

$$P_{V2} = P_0 + \rho g h_2 = 101.325 + (1000 \times 9.81 \times 2.43)/1000 = \mathbf{125.2\ kPa}$$

1.81

Two piston/cylinder arrangements, A and B, have their gas chambers connected by a pipe. Cross-sectional areas are $A_A = 75\ \text{cm}^2$ and $A_B = 25\ \text{cm}^2$ with the piston mass in A being $m_A = 25$ kg. Outside pressure is 100 kPa and standard gravitation. Find the mass m_B so that none of the pistons have to rest on the bottom.

Solution:



Force balance for both pistons: $F\uparrow = F\downarrow$

A: $m_{PA}g + P_0A_A = PA_A$

B: $m_{PB}g + P_0A_B = PA_B$

Same P in A and B gives no flow between them.

$$\frac{m_{PA}g}{A_A} + P_0 = \frac{m_{PB}g}{A_B} + P_0$$

=> $m_{PB} = m_{PA}\ A_A/\ A_B = 25 \times 25/75 =$ **8.33 kg**

1.82

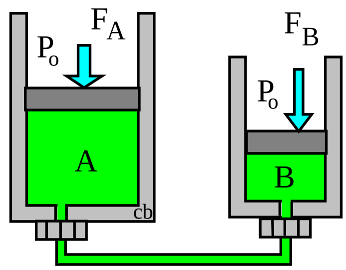
Two hydraulic piston/cylinders are of same size and setup as in Problem 1.81, but with negligible piston masses. A single point force of 250 N presses down on piston A. Find the needed extra force on piston B so that none of the pistons have to move.

Solution:

$A_A = 75\ \text{cm}^2$;

$A_B = 25\ \text{cm}^2$

No motion in connecting pipe: $P_A = P_B$



Forces on pistons balance

$$P_A = P_0 + F_A / A_A = P_B = P_0 + F_B / A_B$$

$$F_B = F_A \times \frac{A_B}{A_A} = 250\ \text{N} \times \frac{25}{75} = \mathbf{83.33\ N}$$

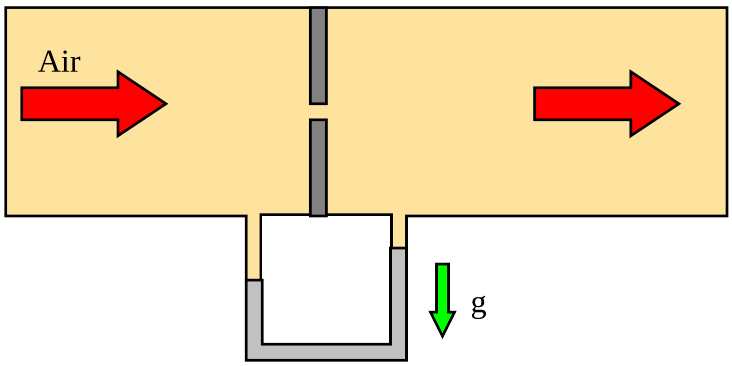
1.83

A piece of experimental apparatus is located where $g = 9.5 \text{ m/s}^2$ 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 (see Problem 1.91 for density) showing a height difference of 200 mm. What is the pressure drop in kPa?

Solution:

$\Delta P = \rho g h$; $\rho_{Hg} = 13600 \text{ kg/m}^3$

$\Delta P = 13\,600 \text{ kg/m}^3 \times 9.5 \text{ m/s}^2 \times 0.2 \text{ m} = 25840 \text{ Pa} = \mathbf{25.84 \text{ kPa}}$

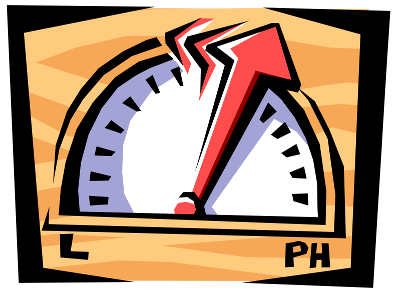


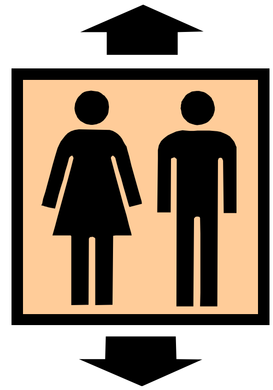
Energy and Temperature

1.84

An escalator brings four people, whose total mass is 300 kg, 25 m up in a building. Explain what happens with respect to energy transfer and stored energy.

The four people (300 kg) have their potential energy raised, which is how the energy is stored. The energy is supplied as electrical power to the motor that pulls the escalator with a cable.





1.85

A car moves at 75 km/h; its mass, including people, is 3200 kg. How much kinetic energy does the car have?

$$KE = ½ \text{ m } \mathbf{V}^2 = ½ \times 3200 \text{ kg} \times \left(\frac{75 \times 1000}{3600}\right)^2 \text{ m}^2/\text{s}^2$$

$$= 694\,444 \text{ J} = \mathbf{694\ kJ}$$

1.86

A 52-kg package 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 package get?

The potential energy is from Eq.1.5

$$pe = gz$$

so for a certain mass we get

$$PE = mgH = 52 \text{ kg} \times 9.81 \text{ m/s}^2 \times 4 \text{ m} = 2040 \text{ J} = \mathbf{2.04 \text{ kJ}}$$

1.87

A car of mass 1775 kg travels with a velocity of 100 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

$$KE = ½\ m\ \mathbf{V}^2 = ½ \times 1775\ kg \times \left(\frac{100 \times 1000}{3600}\right)^2\ m^2/s^2$$

$$= ½ \times 1775 \times 27.778\ Nm = 684\ 800\ J$$

$$= \mathbf{684.8\ kJ}$$

Standard potential energy is

$$POT = mgh$$

$$h = ½\ m\ \mathbf{V}^2 / mg\ = \frac{684\ 800\ Nm}{1775\ kg \times 9.807\ m/s^2} = \mathbf{39.3\ m}$$

1.88

An oxygen molecule with mass m = M m_o = 32 × 1.66 × 10^{-27} kg moves with a velocity of 240 m/s. What is the kinetic energy of the molecule? What temperature does that corresponds to if it has to equal (3/2) *kT* where k is Boltzmans constant and *T* is the absolute temperature in Kelvin.

$$KE = ½ \text{ m } \mathbf{V}^2 = ½ \times 32 \times 1.66 \times 10^{-27} \text{ kg} \times 240^2 \text{ m}^2/\text{s}^2$$
$$= \mathbf{1.53\ E{-}21\ J}$$

So if the KE equals 1.5 kT then we get

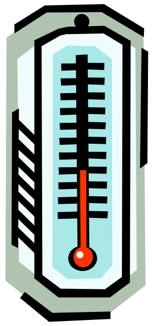
$$KE = 1.5 \text{ kT} = 1.5 \times 1.38065 \times 10^{-23} \text{ J/K} \times T$$

$$T = (2/3) \text{ KE/k} = (2/3) \times 1.53 \text{ E}{-}21 / 1.38065 \times 10^{-23} = \mathbf{73.9\ K}$$

1.89

What is a temperature of $-5^{o}C$ in degrees Kelvin?

Solution:



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

$$T_K = T_C + 273.15 = -5 + 273.15$$
$$= \mathbf{268.15\ K}$$

1.90

The human comfort zone is between 18 and 24^{o}C, what is the range in Kelvin? What is the maximum relative change from the low to the high temperature?

Solution:

$$T_K = T_C + 273.15$$

The range in K becomes from 291.15 to 297.15 K.
The relative change is 6 degrees up from 291.15 K which is

$$\text{Relative change } \% = \frac{6}{291.15} \times 100 = \mathbf{2.06\%}$$

1.91

The density of mercury changes approximately linearly with temperature as

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

so the same pressure difference will result in a manometer reading that is influenced by temperature. If a pressure difference of 100 kPa is measured in the summer at 35°C and in the winter at −15°C, what is the difference in column height between the two measurements?

Solution:

The manometer reading h relates to the pressure difference as

$$\Delta P = \rho\ L\ g \quad \Rightarrow \quad L = \frac{\Delta P}{\rho g}$$

The manometer fluid density from the given formula gives

$$\rho_{su} = 13595 - 2.5 \times 35 = 13507.5 \text{ kg/m}^3$$

$$\rho_{w} = 13595 - 2.5 \times (-15) = 13632.5 \ \text{ kg/m}^3$$

The two different heights that we will measure become

$$L_{su} = \frac{100 \times 10^3}{13507.5 \times 9.807} \frac{\text{kPa (Pa/kPa)}}{(\text{kg/m}^3)\text{ m/s}^2} = 0.7549 \text{ m}$$

$$L_{w} = \frac{100 \times 10^3}{13632.5 \times 9.807} \frac{\text{kPa (Pa/kPa)}}{(\text{kg/m}^3)\text{ m/s}^2} = 0.7480 \text{ m}$$

$\Delta L = L_{su} - L_{w} =$ **0.0069 m = 6.9 mm**

1.92

A mercury thermometer measures temperature by measuring the volume expansion of a fixed mass of liquid Hg due to a change in the density, see problem 1.91. Find the relative change (%) in volume for a change in temperature from 10°C to 20°C.

Solution:

From 10°C to 20°C

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

At 20°C : $\rho_{Hg} = 13595 - 2.5 \times 20 = 13545 \ \text{kg/m}^3$

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

$$\text{Relative Change} = \frac{V_{20} - V_{10}}{V_{10}} = \frac{(m/\rho_{20}) - (m/\rho_{10})}{m/\rho_{10}}$$

$$= \frac{\rho_{10}}{\rho_{20}} - 1 = \frac{13570}{13545} - 1 = \mathbf{0.0018\ (0.18\%)}$$

1.93

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

Solution:

The density change for a change in temperature of 10^oC 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

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

barely measurable.

1.94

Using the freezing and boiling point temperatures for water in both Celsius and Fahrenheit scales, develop a conversion formula between the scales. Find the conversion formula between Kelvin and Rankine temperature scales.

Solution:

$$T_{Freezing} = 0\ ^{o}C = 32\ F; \qquad T_{Boiling} = 100\ ^{o}C = 212\ F$$

$$\Delta T = 100\ ^{o}C = 180\ F \;\Rightarrow\; T_{^oC} = (T_F - 32)/1.8 \quad \text{or} \quad T_F = 1.8\ T_{^oC} + 32$$

For the absolute K & R scales both are zero at absolute zero.

$$T_R = 1.8 \times T_K$$

1.95

The atmosphere becomes colder at higher elevation. As an average the standard atmospheric absolute temperature can be expressed as $T_{atm} = 288 - 6.5 \times 10^{-3} z$, where z is the elevation in meters. How cold is it outside an airplane cruising at 12 000 m expressed in Kelvin and in Celsius?

Solution:

For an elevation of $z = 12\,000$ m we get

$$T_{atm} = 288 - 6.5 \times 10^{-3} z = \mathbf{210\ K}$$

To express that in degrees Celsius we get

$$T_C = T - 273.15 = \mathbf{-63.15^{o}C}$$

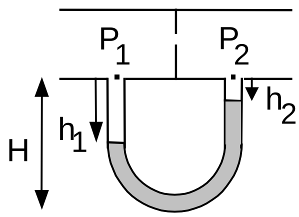
Review Problems

1.96

Repeat problem 1.83 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:



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

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

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

$$P_1 - P_2 = \rho_{Hg}\Delta h_{Hg}g - \rho_{H_2O}\Delta h_{Hg}g$$

$$= (13\,600 \times 0.2 \times 9.5 - 1000 \times 0.2 \times 9.5\,)\ \text{kg/m}^3 \times \text{m} \times \text{m/s}^2$$

$$= (25\,840 - 1900)\ \text{Pa} = 23\,940\ \text{Pa} = \mathbf{23.94\ kPa}$$

1.97

A dam retains a lake 6 m deep. 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:

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

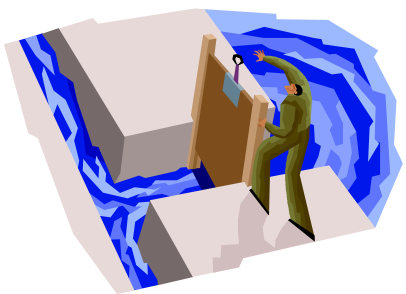
$\Delta P = \rho gh = 997\ kg/m^3 \times 9.807\ m/s^2 \times 6\ m = 58\ 665\ Pa = 58.66\ kPa$

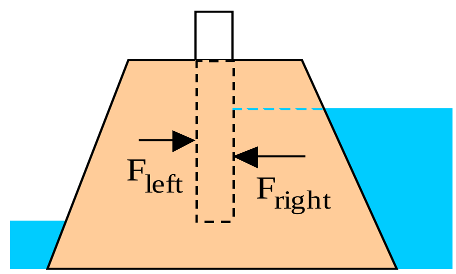
Neglect ΔP in air

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

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

$F_{net} = (P_0 + 0.5\ \Delta P)A - P_0 A = 0.5\ \Delta P\ A = 0.5 \times 58.66 \times 5 \times 6 =$ **880 kN**

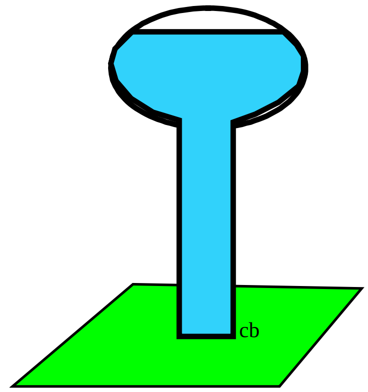




1.98

In the city water tower, water is pumped up to a level 25 m above ground in a pressurized tank with air at 125 kPa over the water surface. This is illustrated in Fig. P1.98. 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:



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

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

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

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

$= 125 + 245.2$

= **370 kPa**

1.99

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.

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

$\Delta P = \rho gh = 997\ kg/m^3 \times 9.807\ m/s^2 \times (150 + 5)\ m$

$= 1\ 515\ 525\ Pa = 1516\ kPa$

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

$\Delta P_{pump} = 1716 – 600 =$ **1116 kPa**

1.100

Two cylinders are connected by a piston as shown in Fig. P1.100. Cylinder A is used as a hydraulic lift and pumped up to 500 kPa. The piston mass is 25 kg and there is standard gravity. What is the gas pressure in cylinder B?

Solution:

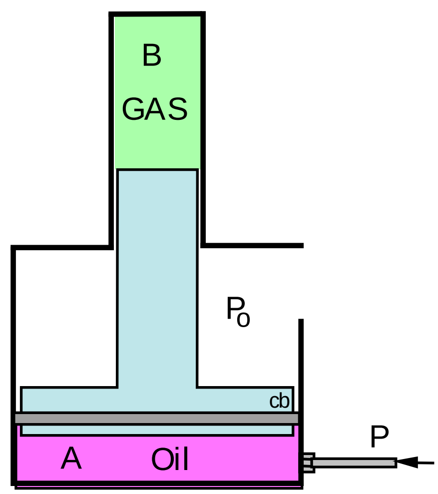
Force balance for the piston: $P_BA_B + m_pg + P_0(A_A - A_B) = P_AA_A$

$A_A = (\pi/4)0.1^2 = 0.00785 \text{ m}^2$; $A_B = (\pi/4)0.025^2 = 0.000\ 491 \text{ m}^2$

$P_BA_B = P_AA_A - m_pg - P_0(A_A - A_B) = 500\times 0.00785 - (25 \times 9.807/1000)$

$- 100\ (0.00785 - 0.000\ 491) = 2.944 \text{ kN}$

$P_B = 2.944/0.000\ 491 = 5996 \text{ kPa} = \mathbf{6.0\ MPa}$



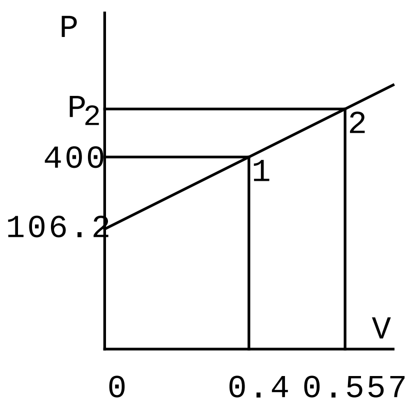
1.101

A 5-kg piston in a cylinder with diameter of 100 mm is loaded with a linear spring and the outside atmospheric pressure of 100 kPa as shown in Fig. P1.101. The spring exerts no force on the piston when it is at the bottom of the cylinder and for the state shown, the pressure is 400 kPa with volume 0.4 L. The valve is opened to let some air in, causing the piston to rise 2 cm. Find the new pressure.

Solution:

A linear spring has a force linear proportional to displacement. F = k x, so the equilibrium pressure then varies linearly with volume: P = a + bV, with an intersect a and a slope b = dP/dV. Look at the balancing pressure at zero volume (V -> 0) when there is no spring force $F = PA = P_oA + m_pg$ and the initial state. These two points determine the straight line shown in the P-V diagram.

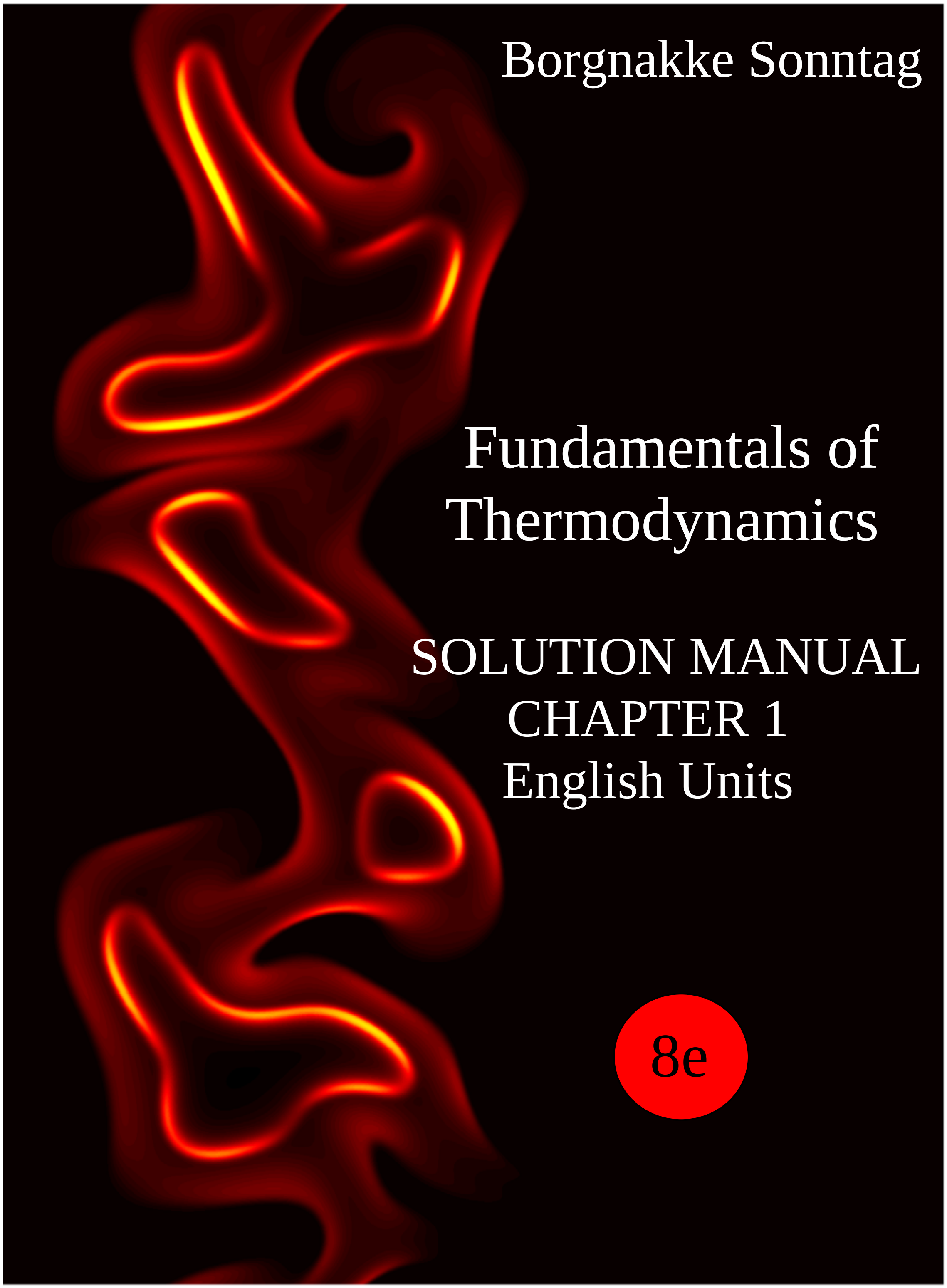
Piston area = $A_p = (\pi/4) \times 0.1^2 = 0.00785 \text{ m}^2$



$$a = P_0 + \frac{m_p g}{A_p} = 100 \text{ kPa} + \frac{5 \times 9.80665}{0.00785} \text{ Pa}$$
$$= 106.2 \text{ kPa} \quad \text{intersect for zero volume.}$$

$$V_2 = 0.4 + 0.00785 \times 20 = 0.557 \text{ L}$$

$$P_2 = P_1 + \frac{dP}{dV} \Delta V$$
$$= 400 + \frac{(400\text{-}106.2)}{0.4 - 0} (0.557 - 0.4)$$
$$= \mathbf{515.3 \ kPa}$$



UPDATED JULY 2013

CHAPTER 1

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Properties and Units	109
Force, Energy and Specific Volume	110-115
Pressure, Manometers and Barometers	116-124
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Concept Problems

1.102E

A mass of 2 lbm has acceleration of 5 ft/s^2, what is the needed force in lbf?

Solution:

Newtons 2nd law: $F = ma$

$$F = ma = 2 \text{ lbm} \times 5 \text{ ft/s}^2 = 10 \text{ lbm ft/s}^2$$
$$= \frac{10}{32.174} \text{ lbf} = \mathbf{0.31 \text{ lbf}}$$

1.103E

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

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

A more accurate value from Table F.3 is $\rho = 848 \text{ lbm/ft}^3$.

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

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

1.104E

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

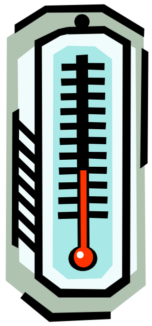
$$m = \rho V = 1205 \text{ lbm/ft}^3 \times 0.13368 \text{ ft}^3$$
$$= 161 \text{ lbm}$$

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

1.105E

What is the temperature of –5F in degrees Rankine?

Solution:



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

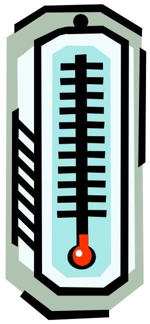
$$T_R = T_F + 459.67 = -5 + 459.67$$
$$= \mathbf{454.7\ R}$$

1.106E

What is the smallest 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



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

1.107E

What is the relative magnitude of degree Rankine to degree Kelvin

Look in Table A.1 p. 757:

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

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

1.108E

Chemical reaction rates genrally double for a 10 K increase in temperature. How large an increase is that in Fahrenheit?

From the Conversion Table A.1: $1 \text{ K} = 1\ ^{o}\text{C} = 1.8 \text{ R} = 1.8 \text{ F}$

So the 10 K increase becomes

$$10 \text{ K} = 18 \text{ F}$$

Properties and Units

1.109E

An apple weighs 0.2 lbm and has a volume of 6 in^3 in a refrigerator at 38 F. What is the apple density? List three intensive and two extensive properties for the apple.

Solution:

$$\rho = \frac{m}{V} = \frac{0.2}{6}\ \frac{\text{lbm}}{\text{in}^3} = 0.0333\ \frac{\text{lbm}}{\text{in}^3} = 57.6\ \frac{\text{lbm}}{\text{ft}^3}$$

Intensive

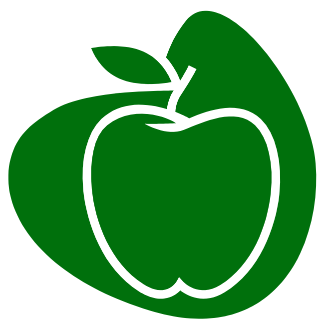
$$\rho = 57.6\ \frac{\text{lbm}}{\text{ft}^3}; \qquad v = \frac{1}{\rho} = 0.0174\ \frac{\text{ft}^3}{\text{lbm}}$$

$$T = 38\ \text{F}; \qquad P = 14.696\ \text{lbf/in}^2$$

Extensive

$$m = 0.2\ \text{lbm}$$

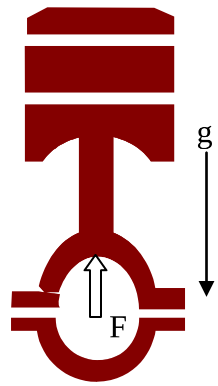
$$V = 6\ \text{in}^3 = 0.026\ \text{gal} = 0.00347\ \text{ft}^3$$



1.110E

A steel piston of 10 lbm is in the standard gravitational field where a force of 10 lbf is applied vertically up. Find the acceleration of the piston.

Solution:



$$F_{up} = ma = F - mg$$

$$a = \frac{F - mg}{m} = \frac{F}{m} - g$$

$$= \frac{10 \text{ lbf}}{10 \text{ lbm}} - 32.174 \text{ ft/s}^2$$

$$= (1 \times 32.174 - 32.174) \text{ ft/s}^2$$

$$= \mathbf{0 \text{ fts}^{-2}}$$

The mass does not move, it is held stationary.

Force, Energy, Density

1.111E

A 2500-lbm car moving at 25 mi/h is accelerated at a constant rate of 15 ft/s^2 up to a speed of 50 mi/h. What are the force and total time required?

Solution:

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

$$\Delta t = \frac{(50 - 25)\text{ mi/h} \times 1609.34 \text{ m/mi} \times 3.28084 \text{ ft/m}}{3600 \text{ s/h} \times 15 \text{ ft/s}^2} = \mathbf{2.44 \text{ sec}}$$

$$F = ma = 2500 \text{ lbm} \times 15 \text{ ft/s}^2 \text{ / } (32.174 \text{ lbm ft /lbf-s}^2\text{)}$$

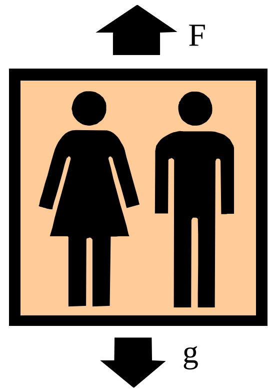
$$= \mathbf{1165 \text{ lbf}}$$

1.112E

An escalator brings four people of total 600 lbm and a 1000 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.



$ma = \sum F = F - mg$

$F = ma + mg = m(a + g)$

$= (1000 + 600) \text{ lbm} \times (3 + 32.174) \text{ ft/s}^2$

$= \mathbf{56\ 278\ lbm\ ft/s^2} = \mathbf{56\ 278\ lbf}$

1.113E

One pound-mass of diatomic oxygen (O_2 molecular weight 32) is contained in a 100-gal tank. Find the specific volume on both a mass and mole basis (v and $\bar{v}$).

Solution:

$$V = 100 \times 231 \text{ in}^3 = (23\,100/12^3) \text{ ft}^3 = 13.37 \text{ ft}^3$$

conversion seen in Table A.1

This is based on the definition of the specific volume

$$v = V/m = 13.37 \text{ ft}^3/1 \text{ lbm} = \mathbf{13.37\ ft^3/lbm}$$

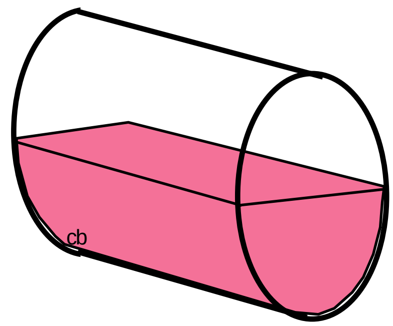
$$\bar{v} = V/n = \frac{V}{m/M} = Mv = 32 \times 13.37 = \mathbf{427.8\ ft^3/lbmol}$$

1.114E

A 30-lbm steel gas tank holds 10 ft^3 of liquid gasoline, having a density of 50 lbm/ft^3. What force is needed to accelerate this combined system at a rate of 15 ft/s^2?

Solution:

$$m = m_{tank} + m_{gasoline}$$
$$= 30 \text{ lbm} + 10 \text{ ft}^3 \times 50 \text{ lbm/ft}^3$$
$$= 530 \text{ lbm}$$



$$F = ma = (530 \text{ lbm} \times 15 \text{ ft/s}^2) / (32.174 \text{ lbm ft/s}^2\text{- lbf}) = \mathbf{247.1 \text{ lbf}}$$

1.115E

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 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.

1.116E

A laboratory room keeps a vacuum of 4 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

$$F = P_{outside}\ A - P_{inside}\ A = \Delta P \times A$$
$$= 4 \text{ in } H_2O \times 6 \text{ ft} \times 3 \text{ ft}$$
$$= 4 \times 0.036126 \text{ lbf/in}^2 \times 18 \text{ ft}^2 \times 144 \text{ in}^2\text{/ft}^2$$
$$= \mathbf{374.6\ lbf}$$

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

1.117E

A 150-lbm human total footprint is 0.5 ft when the person is wearing boots. If snow can support an extra 1 psi, what should the total snow shoe area be?

Force balance: $ma = 0 = PA - mg$

$$A = \frac{mg}{P} = \frac{150 \text{ lbm} \times 32.174 \text{ ft/s}^2}{1 \text{ lbf/in}^2} = \frac{150 \text{ lbm} \times 32.174 \text{ ft/s}^2}{32.174 \text{ lbm-ft/(s}^2\text{in}^2)}$$

$$= \mathbf{150\ in^2} = 1.04 \text{ ft}^2$$

1.118E

A tornado rips off a 1000 ft^2 roof with a mass of 2000 lbm. What is the minimum vacuum pressure needed to do that if we neglect the anchoring forces?

Solution:

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

$$F = P_{inside} A - P_{outside} A = \Delta P\ A$$

That force must overcome the gravitation mg, so the balance is

$$\Delta P\ A = mg$$

$$\Delta P = mg/A = (2000 \text{ lbm} \times 32.174 \text{ ft/s}^2)/1000 \text{ ft}^2$$
$$= 2000/(1000 \times 144) \text{ psi} = \mathbf{0.0139 \text{ psi}}$$

Remember that psi = lbf/in^2.

1.119E

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

Solution:

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

Pressure: 1 psi = 1 lbf/ in^2

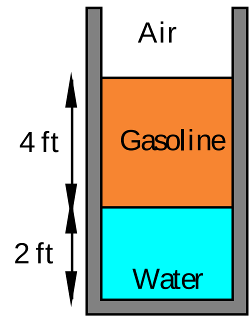
The pressure difference ΔP balances the column of height L so from Eq.2.2

$$\Delta P = \rho g L = 848 \text{ lbm/ft}^3 \times 32.174 \text{ ft/s}^2 \times (3.5/12) \text{ ft}$$
$$= 247.3 \text{ lbf/ft}^2 = (247.3 / 144) \text{ lbf/in}^2$$
$$= \mathbf{1.72\ psi}$$

1.120E

A 7 ft m tall steel cylinder has a cross sectional area of 15 ft^2. At the bottom with a height of 2 ft m is liquid water on top of which is a 4 ft high layer of gasoline. The gasoline surface is exposed to atmospheric air at 14.7 psia. What is the highest pressure in the water?

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

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

The densities from Table F.3 are:

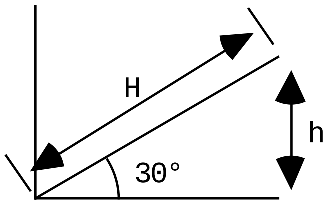
$$\rho_{gasoline} = 46.8 \text{ lbm/ft}^3; \quad \rho_{water} = 62.2 \text{ lbm/ft}^3$$

$$P = 14.7 + [46.8 \times 4 + 62.2 \times 2] \frac{32.174}{144 \times 32.174} = \mathbf{16.86\ lbf/in^2}$$

1.121E

A U-tube manometer filled with water, density 62.3 lbm/ft^3, shows a height difference of 10 in. What is the gauge pressure? If the right branch is tilted to make an angle of 30° with the horizontal, as shown in Fig. P1.77, what should the length of the column in the tilted tube be relative to the U-tube?

Solution:



$$\Delta P = F/A = mg/A = h\rho g$$

$$= \frac{(10/12)\times 62.3 \times 32.174}{32.174 \times 144}$$

$$= P_{gauge} = \mathbf{0.36\ lbf/in^2}$$

$$h = H \times \sin 30°$$

$$\Rightarrow\ H = h/\sin 30° = 2h = 20 \text{ in} = \mathbf{0.833\ ft}$$

1.122E

A piston/cylinder with cross-sectional area of 0.1 ft^2 has a piston mass of 200 lbm resting on the stops, as shown in Fig. P1.50. With an outside atmospheric pressure of 1 atm, what should the water pressure be to lift the piston?

Solution:

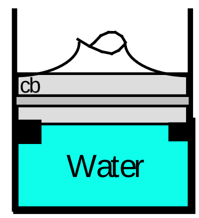
The force acting down on the piston comes from gravitation and the outside atmospheric pressure acting over the top surface.

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

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

$$P = P_0 + \frac{m_p g}{A} = 14.696 + \frac{200 \times 32.174}{0.1 \times 144 \times 32.174}$$

$$= 14.696 \text{ psia} + 13.88 \text{ psia} = \mathbf{28.58\ lbf/in^2}$$



1.123E

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.

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

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

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

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

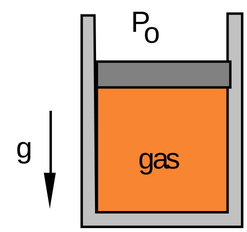
$\Delta P_{pump} = 231.3 – 90 =$ **141.3 psi**

1.124E

A piston, m_p = 10 lbm, is fitted in a cylinder, A = 2.5 in.^{2}, that contains a gas. The setup is in a centrifuge that creates an acceleration of 75 ft/s^2. Assuming standard atmospheric pressure outside the cylinder, find the gas pressure.

Solution:

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



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

$$= 14.696 + \frac{10 \times 75}{2.5 \times 32.174} \; \frac{\text{lbm ft/s}^2}{\text{in}^2} \; \frac{\text{lbf-s}^2}{\text{lbm-ft}}$$

$$= 14.696 + 9.324 = \mathbf{24.02\ lbf/in^2}$$

Temperature

1.125E

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

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

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

1.126E

The atmosphere becomes colder at higher elevation. As an average the standard atmospheric absolute temperature can be expressed as $T_{atm} = 518 - 3.84 \times 10^{-3}\, z$, where z is the elevation in feet. How cold is it outside an airplane cruising at 32 000 ft expressed in Rankine and in Fahrenheit?

Solution:

For an elevation of z = 32 000 ft we get

$$T_{atm} = 518 - 3.84 \times 10^{-3}\, z = \mathbf{395.1\ R}$$

To express that in degrees Fahrenheit we get

$$T_F = T - 459.67 = \mathbf{-64.55\ F}$$

1.127E

The density of mercury changes approximately linearly with temperature as

$$\rho_{Hg} = 851.5 - 0.086\ T \ \text{lbm/ft}^3 \qquad T \ \text{in degrees Fahrenheit}$$

so the same pressure difference will result in a manometer reading that is influenced by temperature. If a pressure difference of 14.7 lbf/in.^{2} is measured in the summer at 95 F and in the winter at 5 F, what is the difference in column height between the two measurements?

Solution:

$$\Delta P = \rho g h \quad \Rightarrow \quad h = \Delta P/\rho g$$

$$\rho_{su} = 843.33 \text{ lbm/ft}^3; \qquad \rho_W = 851.07 \text{ lbm/ft}^3$$

$$h_{su} = \frac{14.7 \times 144 \times 32.174}{843.33 \times 32.174} = 2.51 \text{ ft} = 30.12 \text{ in}$$

$$h_W = \frac{14.7 \times 144 \times 32.174}{851.07 \times 32.174} = 2.487 \text{ ft} = 29.84 \text{ in}$$

$$\Delta h = h_{su} - h_W = 0.023 \text{ ft} = \mathbf{0.28 \ in}$$