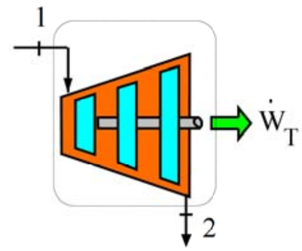
In-Text Concept Questions

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.

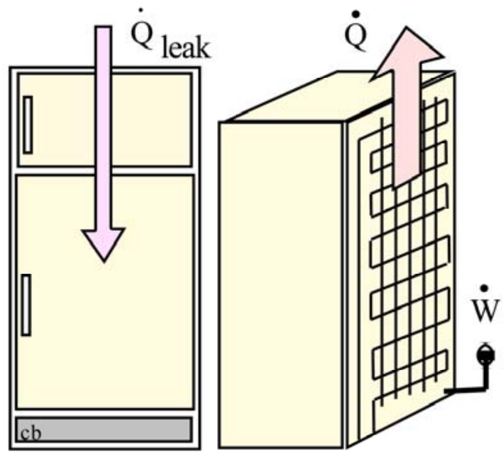


1.b

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

1.f

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

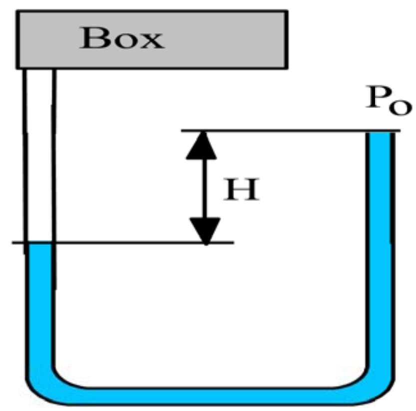
If the fluid density above A is low relative to the manometer fluid then you neglect the pressure variation above position A, say the fluid is a gas like air and the manometer fluid is like liquid water. However, if the fluid above A has a density of the same order of magnitude as the manometer fluid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

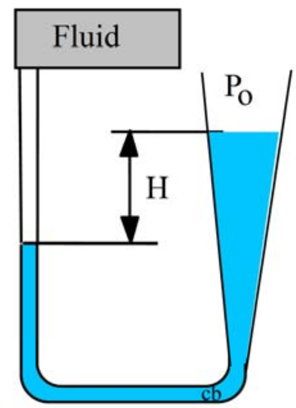
Since the left branch fluid surface feels 110 kPa and the right branch surface is at 100 kPa you must go further down to match the 110 kPa. The right branch has a higher column of fluid.



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^{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.

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

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

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

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 cannot carry that in the standard gravitational field.

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

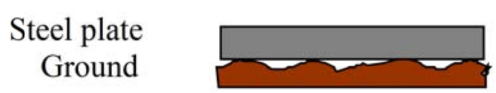
A swimming pool has an evenly distributed pressure at the bottom. Consider a stiff steel plate lying on the ground. Is the pressure below it just as evenly distributed?

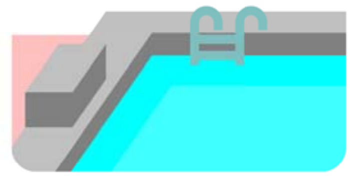
Solution:
The pressure is force per unit area from Eq. 1.3:

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

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

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?

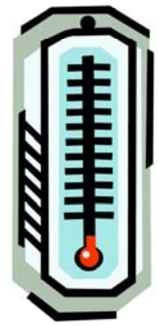
The water pressure right under the ski is not a static pressure but a static plus dynamic pressure that pushes the water away from the ski. The faster you go, the smaller the amount of water is displaced, but at a higher velocity which requires a greater force as the water must accelerated significantly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

1.14

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



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

1.15

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.

1.16

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

Solution:

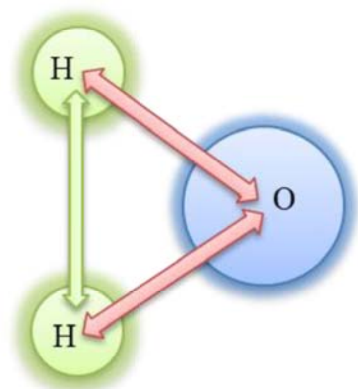
The expansion of the liquid volume with temperature is rather small so by having a larger volume expand with all the volume increase showing in the very small diameter column of fluid greatly increases the signal that can be read.

1.17

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.



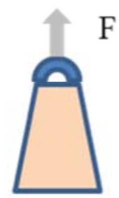
Properties, Units, and Force

1.18

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

$F = ma = mg$

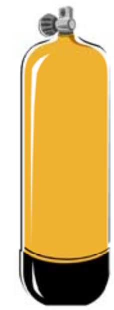
$1 \text{ kp} = 1 \text{ kg} \times 9.807 \text{ m/s}^2 = \mathbf{9.807\ N}$



1.19

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

Table A.2: $M_{CO2} = 44.01$; $M_{Ar} = 39.948$



$$n_{CO2} = m_{CO2} / M_{CO2} = \frac{5}{44.01} = 0.11361 \text{ kmol}$$

$$n_{Ar} = m_{Ar} / M_{Ar} = \frac{7}{39.948} = 0.17523 \text{ kmol}$$

$$n_{tot} = n_{CO2} + n_{Ar} = 0.11361 + 0.17523 = \mathbf{0.289\ kmol}$$

1.20

A steel cylinder of mass 4 kg contains 4 L of liquid water at 25°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: $m = m_{steel} + m_{water} = 4 + 3.988 = \mathbf{7.988\ kg}$

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/ρ), T, P

1.21

The Rover Explorer has a mass of 185 kg, how much does this weigh on the Moon ($g = g_{std}/6$) and on Mars where $g = 3.75\ m/s^2$

Solution:

Density is mass per unit volume

Moon: $F = mg = 185\ kg \times (9.81\ /\ 6)\ m/s^2 = \mathbf{302.5\ N}$

Mars: $F = mg = 185\ kg \times 3.75\ m/s^2 = \mathbf{693.8\ N}$

The 185 kg on earth will give a weight of 1815 N = 185 kp

1.22

A 1700-kg car moving at 80 km/h is decelerated at a constant rate of 4 m/s^2 to a speed of 20 km/h. What are the force and total time required?

Solution:

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

$$\Delta t = \frac{\Delta\mathbf{V}}{a} = \frac{(80 - 20)\ \text{km/h} \times 1000\ \text{m/km}}{3600\ \text{s/h} \times 4\ \text{m/s}^2} = \mathbf{4.167\ sec}$$

$$F = ma = 1700\ \text{kg} \times 4\ \text{m/s}^2 = \mathbf{6800\ N}$$

1.23

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:

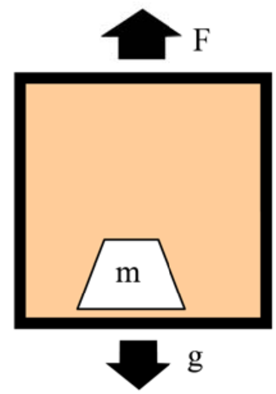
The total mass moves upwards with an acceleration plus the gravitations acts with a force pointing down.

$ma = \sum F = F - mg$

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

$= (750 + 450)\ kg \times (1 + 9.81)\ m/s^2$

$=$ **12 972 N**



1.24

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

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

Solve for x

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

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.

Specific Volume

1.25

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:

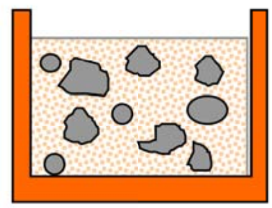
Specific volume and density are ratios of total mass and total volume.

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

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

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

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



$$V_{TOT} = V_{stone} + V_{sand} + V_{liq} = 0.1455 + 0.1333 + 0.2 = 0.4788\ m^3$$

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

$$\rho = 1/v = m_{TOT}/V_{TOT} = 799.4\ kg /0.4788\ m^3 = \mathbf{1670\ kg/m^3}$$

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 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:

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

$$= 1.15\ kg/m^3\ [\ 5 - \frac{900}{2400}\ ]\ m^3 = 1.15\ \times 4.625\ kg = \mathbf{5.32\ kg}$$

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

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.

Pressure

1.28

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?

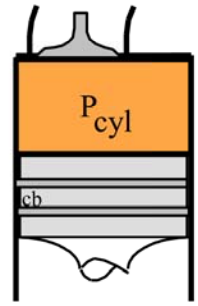
Force balance: $ma = 0 = PA - mg$

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

1.29

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?

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



1.30

The piston cylinder in Fig. P1.29 has a diameter of 10 cm, inside pressure 735 kPa. What is the force holding the massless piston up as the piston lower side has P_0 besides the force?

Solution:

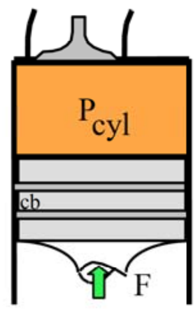
Force acting on the mass by the inside pressure

$$F\downarrow = P\,A$$

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

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

$$F = (735 - 101)\ kPa \times 0.007854\ m^2 = \mathbf{4.98\ kN}$$



1.31

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

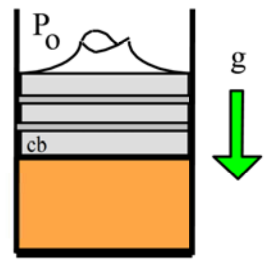
$$F\uparrow = P\,A = F\downarrow = mg$$
$$A = \pi\, r^2 = \pi\, D^2/4$$
$$PA = P\,\pi\, D^2/4 = mg \quad \Rightarrow \qquad D^2 = \frac{4mg}{P\,\pi}$$

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

1.32

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 2500 kPa.

Solution:



Force balance:

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

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

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

$= 0.01227 \text{ m}^2$

$$m = (P - P_0)\frac{A}{g} = (\ 2500 - 100\ ) \text{ kPa} \times 1000 \text{ Pa/kPa} \times \frac{0.01227}{9.80665}\frac{\text{m}^2}{\text{m/s}^2}$$

$= \mathbf{3003\ kg}$

1.33

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

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

1.34

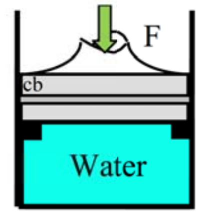
A piston/cylinder with cross sectional area of 0.01 m^2 has a piston mass of 65 kg plus a force of 800 N resting on the stops, as shown in the figure. With an outside atmospheric pressure of 101 kPa, what should the water pressure be to lift the piston?

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



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

$$= 101 \text{ kPa} + \frac{65 \times 9.80665}{0.01 \times 1000} + \frac{800 \text{ N}}{0.01 \text{ m}^2 \times 1000 \text{ Pa/kPa}}$$

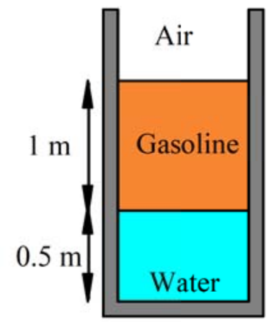
$$= 101 \text{ kPa} + 63.74 \text{ kPa} + 80 \text{ kPa} = \mathbf{244.7\ kPa}$$

1.35

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. P1.35. 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:

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

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

$= \mathbf{113.2\ kPa}$

1.36

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

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

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

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

$$= \rho_{H2O}Vg - mg - F$$

$$V = (mg + F)/\ \rho_{H2O}g = (m + F/g)/\ \rho_{H2O}$$

$$= (250\ \text{kg} + 1000\ \text{N}/9.81\ \text{m/s}^2)\ /\ 997\ \text{kg/m}^3$$

$$= \mathbf{0.353\ m^3}$$

Fig. 2.28b
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1.37

An floating oil rig is anchored in the seabed with cables giving a net pull of 10 000 kN down. How large a water displacement volume does that lead to?

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

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

$$V = F/\rho_{H2O}g = 10\,000 \text{ kN} / (9.81 \text{ m/s}^2 \times 997 \text{ kg/m}^3)$$

$$= \mathbf{1022\ m^3}$$

Notice this is just the extra displacement volume needed to balance the cable pull. More displacement volume is needed to hold the mass of the rig itself up.

1.38

At the beach, atmospheric pressure is 1025 mbar. You dive 15 m down in the ocean and you later climb a hill up to 450 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).

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

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

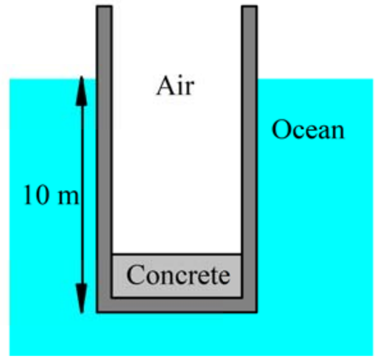
$$P_{hill} = P_0 - \Delta P = 1025 \times 100 \text{ Pa} - 1.18 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 450 \text{ m}$$

$$= 0.9729 \times 10^5 \text{ Pa} = \mathbf{97.3\ kPa}$$

1.39

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. P1.39. 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

$$m_{concrete} = (\rho_{ocean}hA - m_{tank}) = 997 \text{ kg/ m}^3 \times 10 \text{ m} \times 3 \text{ m}^2 - 10\ 000 \text{ kg}$$
$$= \mathbf{19\ 910\ kg}$$

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.