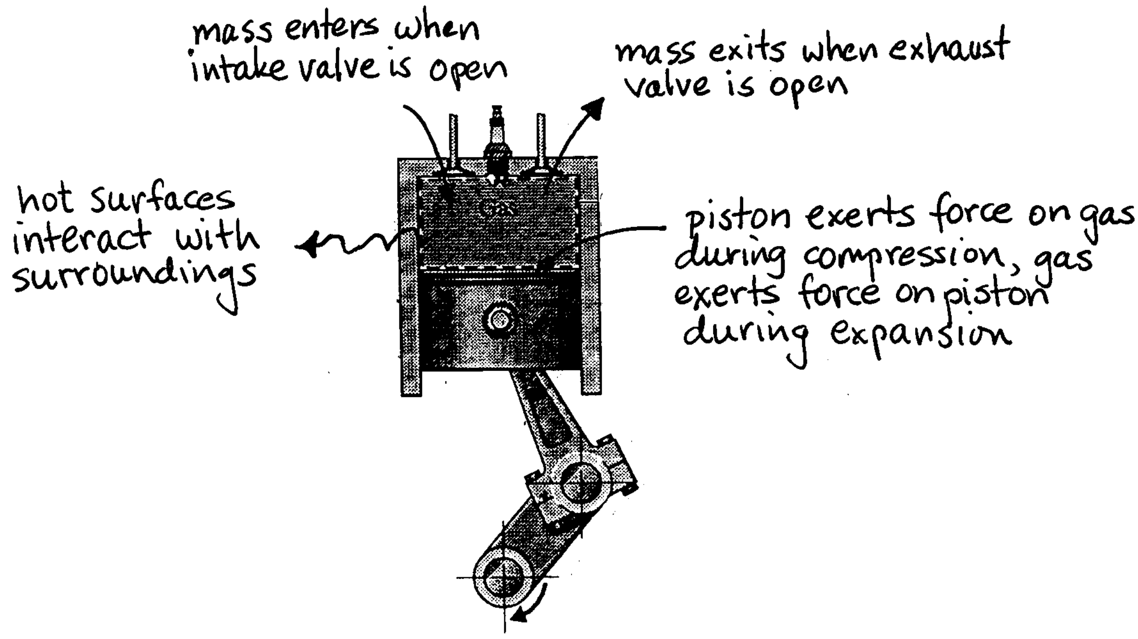
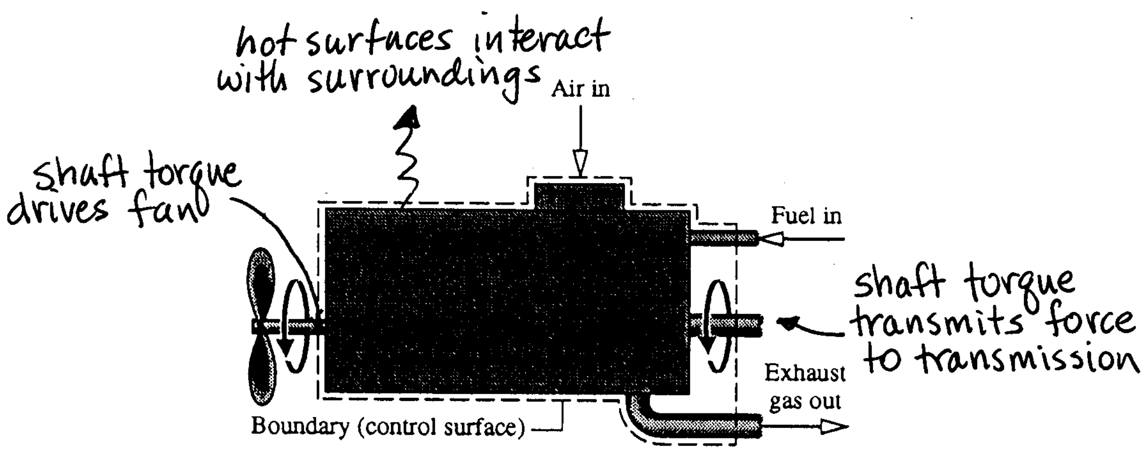
CHAPTER

2

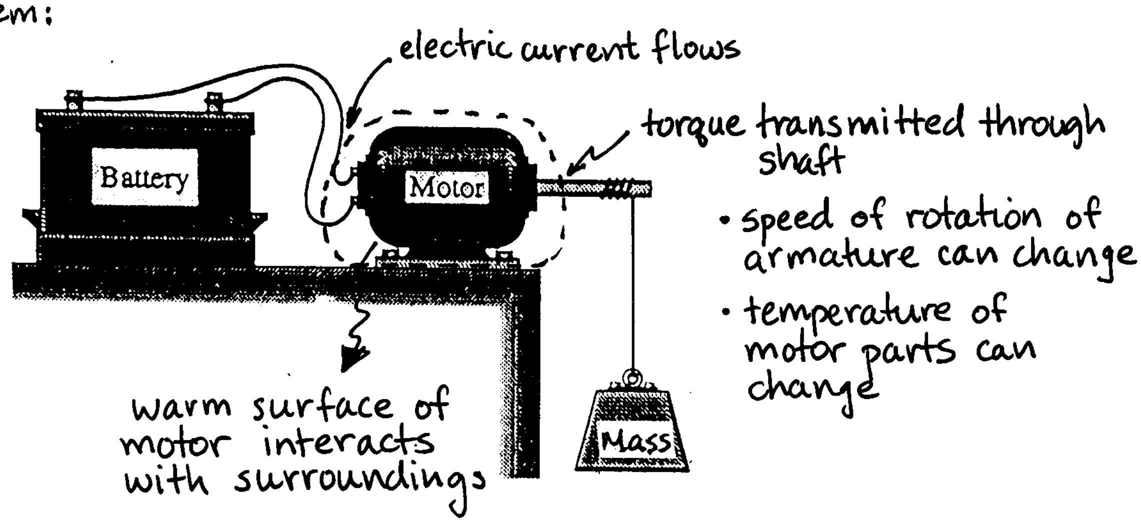
PROBLEM 2.1


mass enters when intake valve is open
mass exits when exhaust valve is open
hot surfaces interact with surroundings
piston exerts force on gas during compression, gas exerts force on piston during expansion
Gas

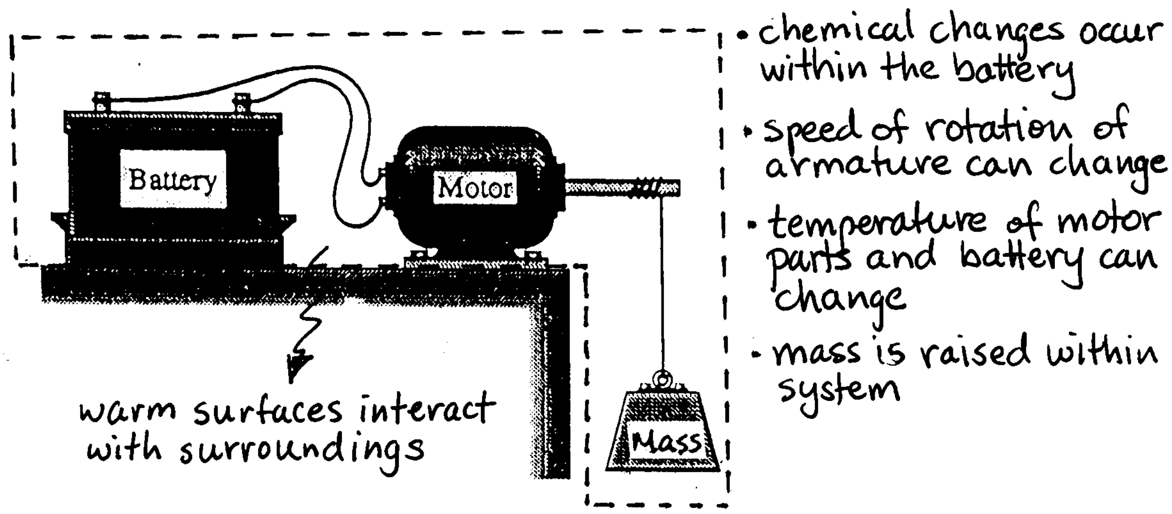

hot surfaces interact with surroundings
Air in
shaft torque drives fan
Fuel in
shaft torque transmits force to transmission
Exhaust gas out
Boundary (control surface)

PROBLEM 2.2

Motor as system:

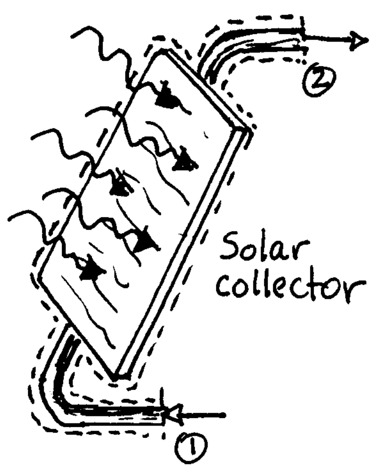


Enlarged system:



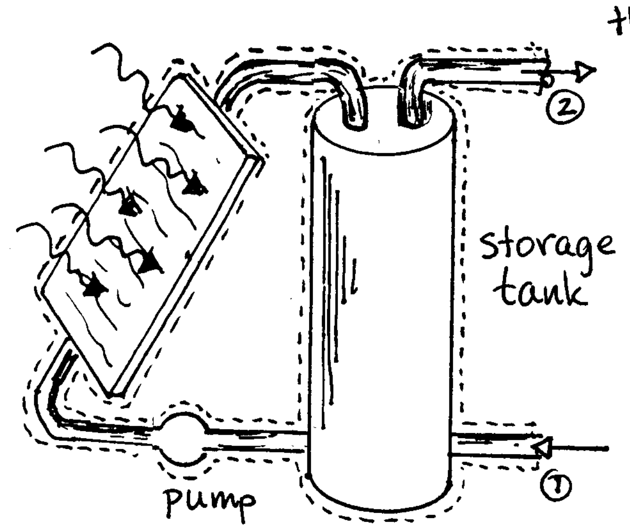
COMMENT: The shaft torque and current flow interactions become internal to the enlarged system.

PROBLEM 2.3



A control volume encloses the solar collector.

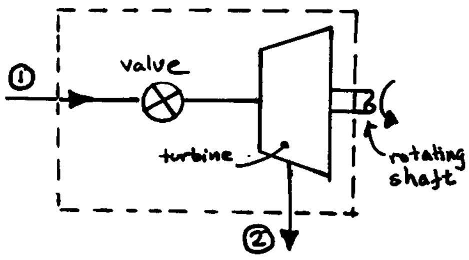
- Cool water enters the collector at ①, and hot water exits at ②.
- solar radiation impinges on the front of the collector.
- Warm surfaces of the collector interact with the surroundings.
- some of the incoming radiation is reflected away, and some is absorbed in the collector surface.



A control volume encloses the solar collector, the tank, and the interconnected piping.

- Cold water enters the tank at ①, and hot water exits at ②.
- Warm surfaces of the collector, storage tank, and interconnected piping interact with the surroundings.
- Solar radiation impinges on the front of the collector; some is reflected and some is absorbed.
- The temperature of the water in the storage tank changes with time.

PROBLEM 2.4



A control volume encloses the valve and turbine.

- Steam enters at 1 and exits at 2.
- A torque is transmitted through the rotating shaft.
- Warm surfaces of the turbine interact with the surroundings.

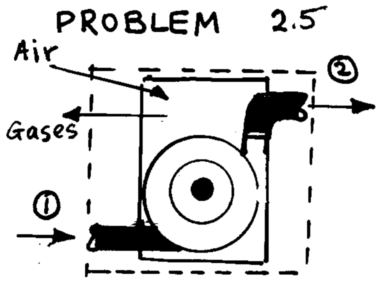
Within the control volume, steam flows across the valve and through the turbine blades.

When the generator is included in the control volume,

- Steam enters at 1 and exits at 2.
- Warm surfaces of the turbine and the generator interact with the surroundings.
- Electric current flows from the generator.

Note that the transmitted torque does not cross the boundary of the enlarged control volume.

PROBLEM 2.5



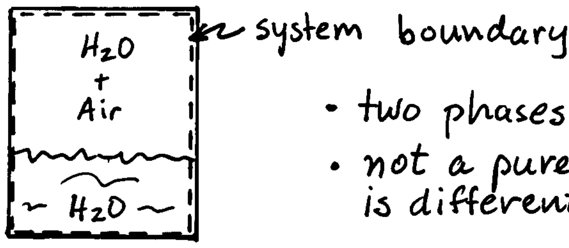
A control volume encloses the engine-driven pump.

- Water enters at 1 and exits at 2
- Air for combustion of the on-board fuel enters, and combustion gases exit.
- Warm surfaces of the pump interact with the surroundings.

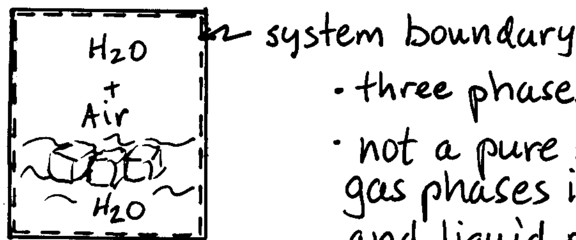
Within the pump, a piston is kept in motion within a cylinder owing to combustion of the on-board fuel. The piston motion is harnessed to pump the liquid. The amount of fuel within the system decreases with time.

When the hose and nozzle are included, a high-speed water jet exits the extended control volume at the nozzle exit,

PROBLEM 2.6

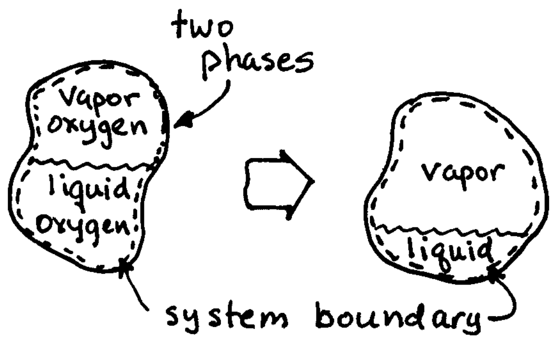


- two phases are present (liquid and gas).
- not a pure substance because composition is different in each phase.



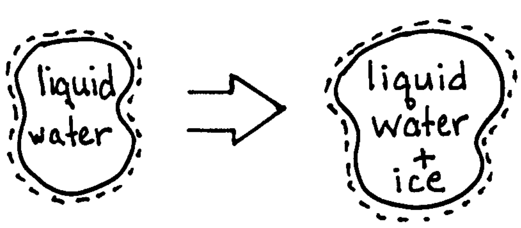
- three phases are present (solid, liquid, and gas).
- not a pure subtance because composition of gas phases is different than that of the solid and liquid phases.

PROBLEM 2.7



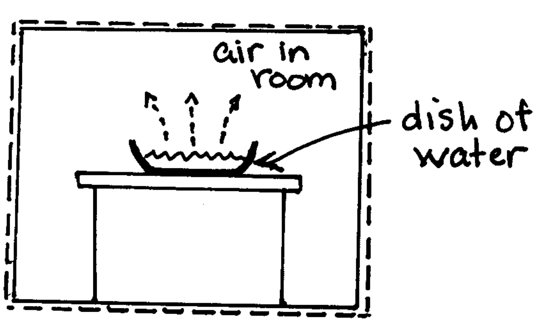
The system is a pure substance. Although the liquid is vaporized, the system remains fixed in chemical composition and is chemically homogeneous.

PROBLEM 2.8



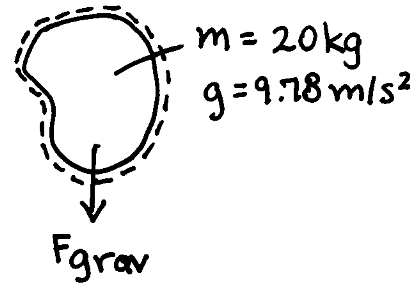
The system is a pure substance. Although the phases change, the system remains of fixed chemical composition and is chemically homogeneous.

PROBLEM 2.9



The system is not a pure substance during the process since the composition of the gas phase changes as water evaporates into the air. Once all of the water evaporates, the gas phase comes to equilibrium and the composition becomes homogeneous. At this point, the gas phase can be treated as a pure substance.

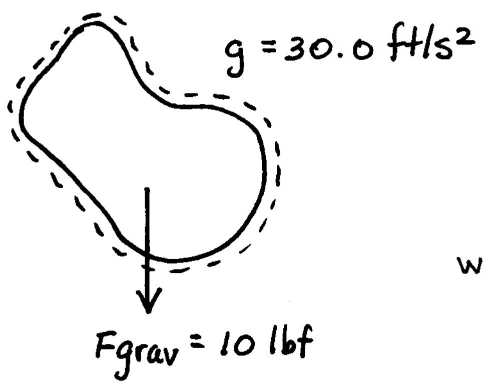
PROBLEM 2.10



$$F_{grav} = mg = (20\,kg)(9.78\,\tfrac{m}{s^2})\left|\frac{1\,N}{1\,kg\cdot m/s^2}\right|$$

$$= 195.6\,N \longleftarrow F_{grav}$$

PROBLEM 2.11



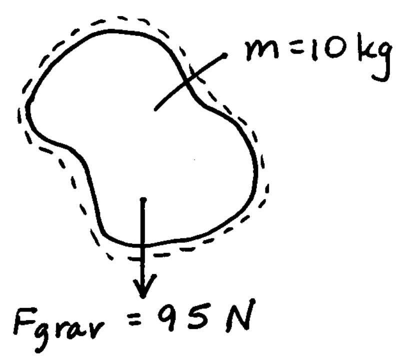
$$m = \frac{F_{grav}}{g} = \left(\frac{10\,lbf}{30.0\,ft/s^2}\right)\left|\frac{32.2\,lb\cdot ft/s^2}{1\,lbf}\right|$$

$$= 10.73\,lb \longleftarrow m$$

With Eq. 2.7

$$m = 10.73\,lb\left|\frac{1\,slug}{32.1740\,lb}\right| = 0.333\,slug$$

PROBLEM 2.12



(a) $$g_{local} = \frac{F_{grav}}{m} = \left(\frac{95\,N}{10\,kg}\right)\left|\frac{1\,kg\cdot m/s^2}{1\,N}\right|$$

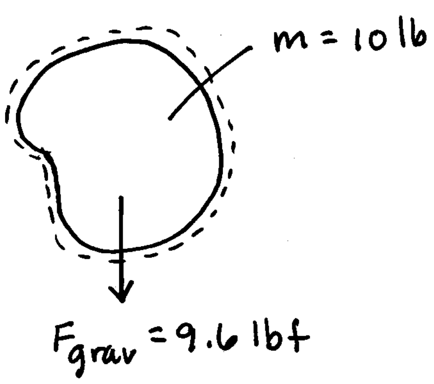
$$= 9.5\,m/s^2 \longleftarrow g_{local}$$

(b) mass is unchanged. $\longleftarrow m$

$$F_{grav} = mg = (10\,kg)(9.81\,m/s^2)\left|\frac{1\,N}{1\,kg\cdot m/s^2}\right|$$

$$= 98.1\,N \longleftarrow F_{grav}$$

PROBLEM 2.13



(a) $$g_{local} = \frac{F_{grav}}{m} = \left(\frac{9.6\,lbf}{10\,lb}\right)\left|\frac{32.2\,lb\cdot ft/s^2}{1\,lbf}\right|$$

$$= 30.9\,ft/s^2 \longleftarrow g_{local}$$

(b) mass is unchanged. $\longleftarrow m$

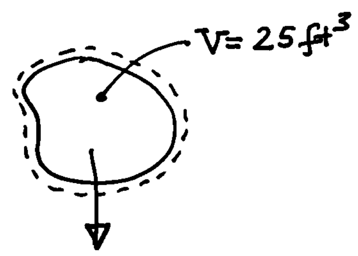
$$F_{grav} = mg = (10\,lb)(32.2\,\tfrac{ft}{s^2})\left|\frac{1\,lbf}{32.2\,lb\cdot ft/s^2}\right|$$

$$= 10\,lbf \longleftarrow F_{grav}$$

Using Eq. 2.7

$$m = 10\,lb\left|\frac{1\,slug}{32.1740\,lb}\right| = 0.31\,slug$$

PROBLEM 2.14



$F_{grav} = 3.5\,lbf$
$g_{moon} = 5.47\,ft/s^2$
$g_{mars} = 12.86\,ft/s^2$

In general, $F_{grav} = m\,g$. So,

$$m = \frac{F_{grav}}{g} \qquad (*)$$

Since the mass is the same on mars as on the moon,

$$\left(\frac{F_{grav}}{g}\right)_{mars} = \left(\frac{F_{grav}}{g}\right)_{moon}$$

Accordingly

$$(F_{grav})_{mars} = \left(\frac{g_{mars}}{g_{moon}}\right)(F_{grav})_{moon}$$

$$= \left(\frac{12.86\,ft/s^2}{5.47\,ft/s^2}\right)(3.5\,lbf) = 8.23\,lbf \longleftarrow$$

The density is $\rho = m/V$. Applying Eq. (*) with data on mars

$$m = \left(\frac{8.23\,lbf}{12.86\,ft/s^2}\right)\left|\frac{32.2\,lb\cdot ft/s^2}{1\,lbf}\right| = 20.61\,lb$$

Then

$$\rho = \frac{20.61\,lb}{25\,ft^3} = 0.824\,\frac{lb}{ft^3} \longleftarrow$$

PROBLEM 2.15

Eq. 2.10 is used on both parts: $n = m/M$, Where M is from Tables T-1.

(a) $m = Mn$, $n = 20\,kmol$:

Air: $m = (28.97\,kg/kmol)(20\,kmol) = 579.4\,kg$

C: $m = (12.01\,kg/kmol)(20\,kmol) = 240.2\,kg$

H_2O: $m = (18.02\,kg/kmol)(20\,kmol) = 360.4\,kg$

CO_2: $m = (44.01\,kg/kmol)(20\,kmol) = 880.2\,kg$

(b) $n = m/M$, $m = 50\,lb$:

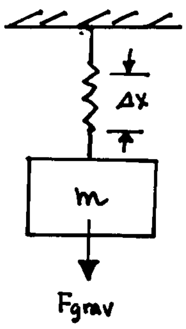
H_2: $n = (50\,lb)/(2.016\,lb/lbmol) = 24.802\,lbmol$

N_2: $n = (50\,lb)/(28.01\,lb/lbmol) = 1.785\,lbmol$

NH_3: $n = (50\,lb)/(17.03\,lb/lbmol) = 2.936\,lbmol$

C_3H_8: $n = (50\,lb)/(44.09\,lb/lbmol) = 1.134\,lbmol$

PROBLEM 2.16



For a linear spring, $F_{spring} = K(\Delta x)$, where Δx is the spring extension. Since $F_{spring} = F_{grav} = mg$, we have $K(\Delta x) = mg$. Since m and K are independent of location, the local acceleration of gravity is proportional to the deflection. Thus

mars:

$$\frac{g_{mars}}{g_{earth}} = \frac{(\Delta x)_{mars}}{(\Delta x)_{earth}} = \frac{0.116\text{ in}}{0.291\text{ in}} \Rightarrow g_{mars} = \left(\frac{0.116}{0.291}\right)\left(32.174\frac{ft}{s^2}\right)$$

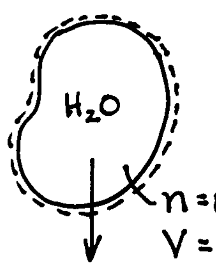
$$= 12.825\frac{ft}{s^2}$$

moon:

$$\frac{g_{moon}}{g_{earth}} = \frac{(\Delta x)_{moon}}{(\Delta x)_{earth}} \Rightarrow (\Delta x)_{moon} = \left(\frac{g_{moon}}{g_{earth}}\right)(\Delta x)_{earth}$$

$$= \left(\frac{5.471}{32.174}\right)(0.291\text{ in}) = 0.049\text{ in}$$

PROBLEM 2.17



$n = 0.5$ lbmol
$V = 0.145\ ft^3$
F_{grav} $g = 30.5\ ft/s^2$

From Table T-1E : $M = 18.02$ lb/lbmol

$$F_{grav} = mg = nMg$$

$$= (0.5\text{ lbmol})\left(18.02\frac{lb}{lbmol}\right)\left(30.5\frac{ft}{s^2}\right)\left|\frac{1\text{ lbf}}{32.2\text{ lb}\cdot ft/s^2}\right|$$

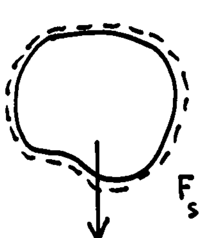
$$= 8.534\text{ lbf} \leftarrow F_{grav}$$

$$\rho_{ave} = \frac{m}{V} = \frac{(0.5)(18.02)}{(0.145)} = 62.14\text{ lb}/ft^3 \leftarrow \rho_{ave}$$

With Eq. 2.7,

$$\rho_{ave} = 62.14\frac{lb}{ft^3}\left|\frac{1\text{ slug}}{32.1740\text{ lb}}\right| = 1.93\frac{slug}{ft^3}$$

PROBLEM 2.18



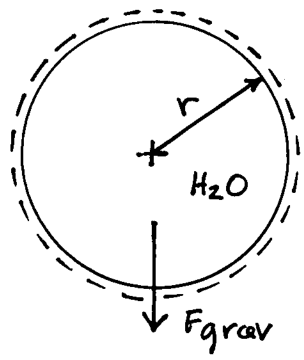
$F_{space} = 42$ N
weight $g_{space} = 6\ m/s^2$
$g_{earth} = 9.81\ m/s^2$

$$\left.\begin{array}{l} F_{space} = m\,g_{space} \\ F_{earth} = m\,g_{earth} \end{array}\right\} \quad \frac{F_{space}}{g_{space}} = \frac{F_{earth}}{g_{earth}}$$

$$F_{earth} = F_{space}\left(\frac{g_{earth}}{g_{space}}\right) = (42\text{ N})\left(\frac{9.81}{6}\right)$$

$$= 68.67\text{ N} \leftarrow F_{earth}$$

PROBLEM 2.19



$r = 30$ ft
$\rho_{H_2O} = 62.4$ lb/ft^3
$g = 32.1$ ft/s^2

The mass of water is $m = \rho V$, where V is the volume of the spherical tank. Thus

$$V = \frac{4}{3}\pi r^3 = \left(\frac{4}{3}\right)(\pi)(30\text{ ft})^3 = 1.131\times10^5\text{ ft}^3$$

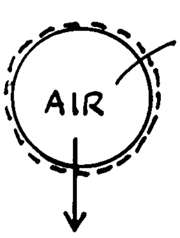
and the mass is

$$m = \rho V = \left(62.4\ \frac{\text{lb}}{\text{ft}^3}\right)(1.131\times10^5)\text{ ft}^3$$
$$= 7.06\times10^6\text{ lb} \longleftarrow m$$

The weight is

$$F_{grav} = mg = (7.06\times10^6\text{ lb})\left(32.1\ \frac{\text{ft}}{\text{s}^2}\right)\left|\frac{1\text{ lbf}}{32.2\text{ lb}\cdot\text{ft/s}^2}\right|$$
$$= 7.04\times10^6\text{ lbf} \longleftarrow F_{grav}$$

PROBLEM 2.20



$d = 10$ ft
$v = 15.1$ ft^3/lb
$g = 31.0$ ft/s^2

$$V = \frac{\pi d^3}{6} = \frac{\pi(10^3)\text{ft}^3}{6} = 523.6\text{ ft}^3$$

$$m = \frac{V}{v} = \frac{523.6\text{ ft}^3}{15.1\text{ ft}^3/\text{lb}} = 34.68\text{ lb}$$

$$F_{grav} = mg = (34.68\text{ lb})\left(31.0\ \frac{\text{ft}}{\text{s}^2}\right)\left|\frac{1\text{ lbf}}{32.2\text{ lb}\cdot\text{ft/s}^2}\right|$$
$$= 33.39\text{ lbf} \longleftarrow F_{grav}$$

PROBLEM 2.21

$\mathcal{V} = 20 m^3$

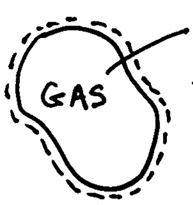
initial mass : $m_1 = 25 kg$

final mass : $m_2 = 30 kg$

Using $v = \frac{\mathcal{V}}{m}$, we get

$$v_1 = \frac{20 m^3}{25 kg} = 0.8 \frac{m^3}{kg} , \quad v_2 = \frac{20 m^3}{30 kg} = 0.67 \frac{m^3}{kg}$$

PROBLEM 2.22



$m = 2 kg$

$p v^{1.3} = \text{const.}$

$p_1 = 1 \text{ bar}$, $v_1 = 0.5 m^3/kg$

$p_2 = 0.25 \text{ bar}$

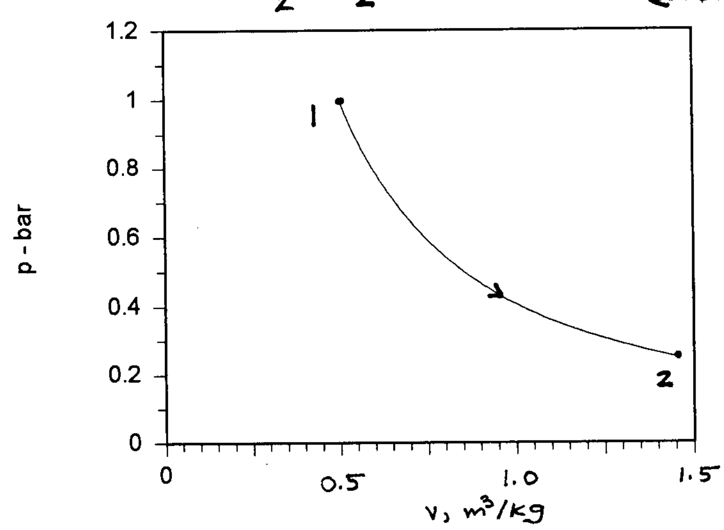
From the pressure-specific volume relation

$$v_2 = \left(\frac{p_1}{p_2}\right)^{\frac{1}{1.3}} v_1 = \left(\frac{1}{0.25}\right)^{\frac{1}{1.3}} (0.5 m^3/kg)$$

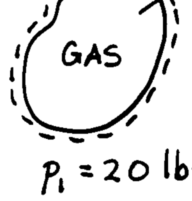
$$= 1.4524 m^3/kg$$

$$V_2 = v_2 m = 2.905 m^3$$

V_2



PROBLEM 2.23



$m = 1 lb$

$pV^n = \text{const.}$

$p_1 = 20 \text{ lbf/in}^2$, $V_1 = 10 ft^3$

$p_2 = 100 \text{ lbf/in}^2$

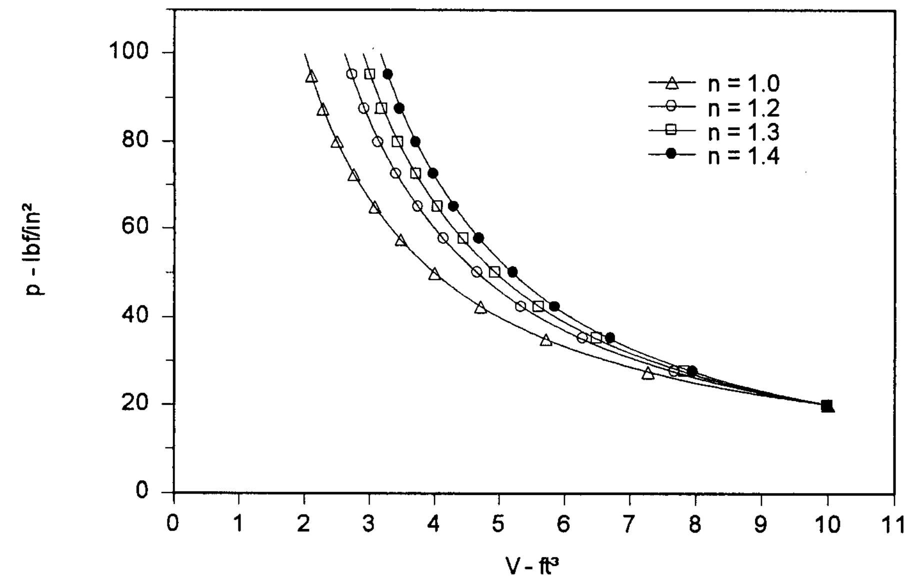
From the pressure-volume relation

$$V_2 = \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} V_1 = \left(\frac{20}{100}\right)^{\frac{1}{n}} (10 ft^3)$$

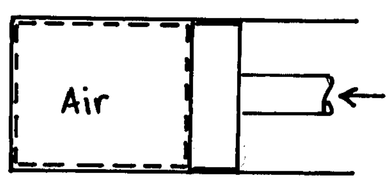
$$\left.\begin{array}{l} n = 1; \ V_2 = 2 ft^3 \\ n = 1.2; \ V_2 = 2.615 ft^3 \\ n = 1.3; \ V_2 = 2.900 ft^3 \\ n = 1.4; \ V_2 = 3.168 ft^3 \end{array}\right\}$$

V_2

PROBLEM 2.23 (Continued)



PROBLEM 2.24



$p_1 = 20$ lbf/in²
$V_1 = 1.5$ ft³
$p_2 = 100$ lbf/in²
$V_2 = 0.5$ ft³

The pressure-volume relation is linear during the process. Thus

$$p = p_1 + \left(\frac{p_2 - p_1}{V_2 - V_1}\right)(V - V_1)$$

Or, using given data

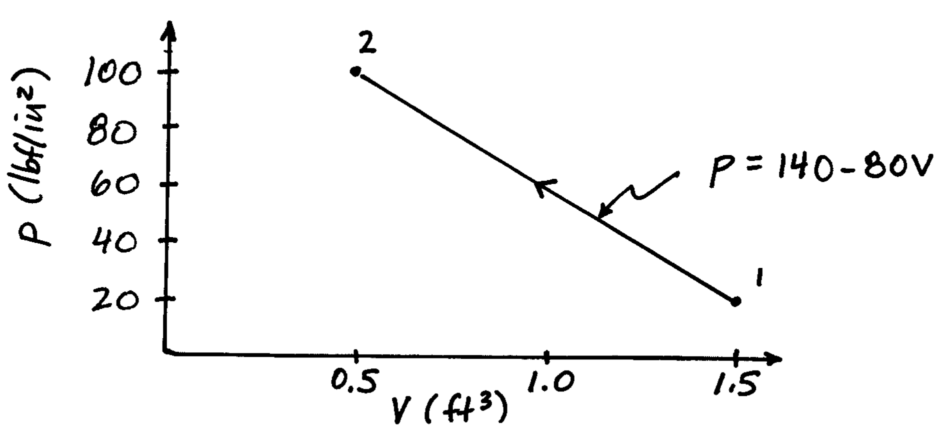
$$p = 20 \frac{\text{lbf}}{\text{in}^2} + \frac{(100-20)\ \text{lbf/in}^2}{(0.5-1.5)\ \text{ft}^3}(V - 1.5)\ \text{ft}^3$$

$$= 140 - 80V$$

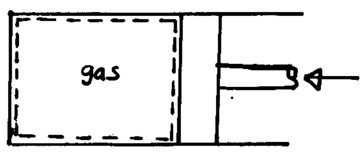
When $V = 1.2$ ft³

$$p = 140 - 80(1.2) = 44\ \text{lbf/in}^2 \longleftarrow \underline{p}$$

On p-V coordinates



PROBLEM 2.25



$p_1 = 1$ bar
$V_1 = 1$ L
$p_2 = 4$ bar

(a) The process is described by pV = constant. The constant can be evaluated using data at state 1:

$$pV = \text{constant} = p_1 V_1 = (1\,\text{bar})(1\,\text{L}) = 1\ \text{bar}\cdot\text{L}$$

So, for every state during the process, we have the relation

$$pV = 1\ \text{bar}\cdot\text{L}$$

When $p = 3$ bar,

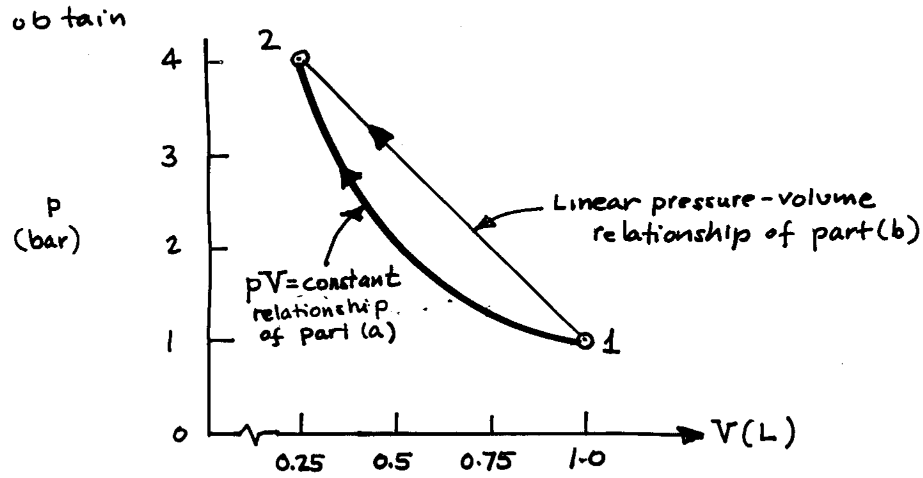
$$V = \frac{1\ \text{bar}\cdot\text{L}}{3\ \text{bar}} = 0.33\ \text{L}$$

When $p = 4$ bar, $$V_2 = \frac{1\ \text{bar}\cdot\text{L}}{4\ \text{bar}} = 0.25\ \text{L}$$

Plotting the relation on pressure-volume coordinates we use

$$p = \frac{1\ \text{bar}\cdot\text{L}}{V}$$

to obtain

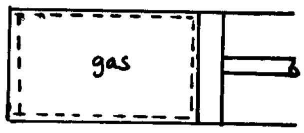


(b) For comparison, the linear pressure-volume relationship is shown on the plot above. The volume corresponding to $p = 3$ bar can be obtained simply using the slope of the straight line between 1 and 2:

$$|\text{slope}| = \frac{(4-1)\,\text{bar}}{(1.0-0.25)\,\text{L}} = \frac{(3-1)}{(1.0-V)} \Rightarrow V = 0.5\ \text{L}$$

This value also can be read from the plot.

PROBLEM 2.26



Thermodynamic cycle:

1-2: $pV = \text{constant}$

$p_1 = 1\text{ bar},\ V_1 = 1\text{ m}^3,\ V_2 = 0.2\text{ m}^3$

2-3 $p = \text{constant},\ V > V_2$ (expansion), $V_3 = 1.0\text{ m}^3$

3-1 $V = \text{constant}$

For process 1-2, $pV = \text{constant}$. The constant can be evaluated using data at state 1:

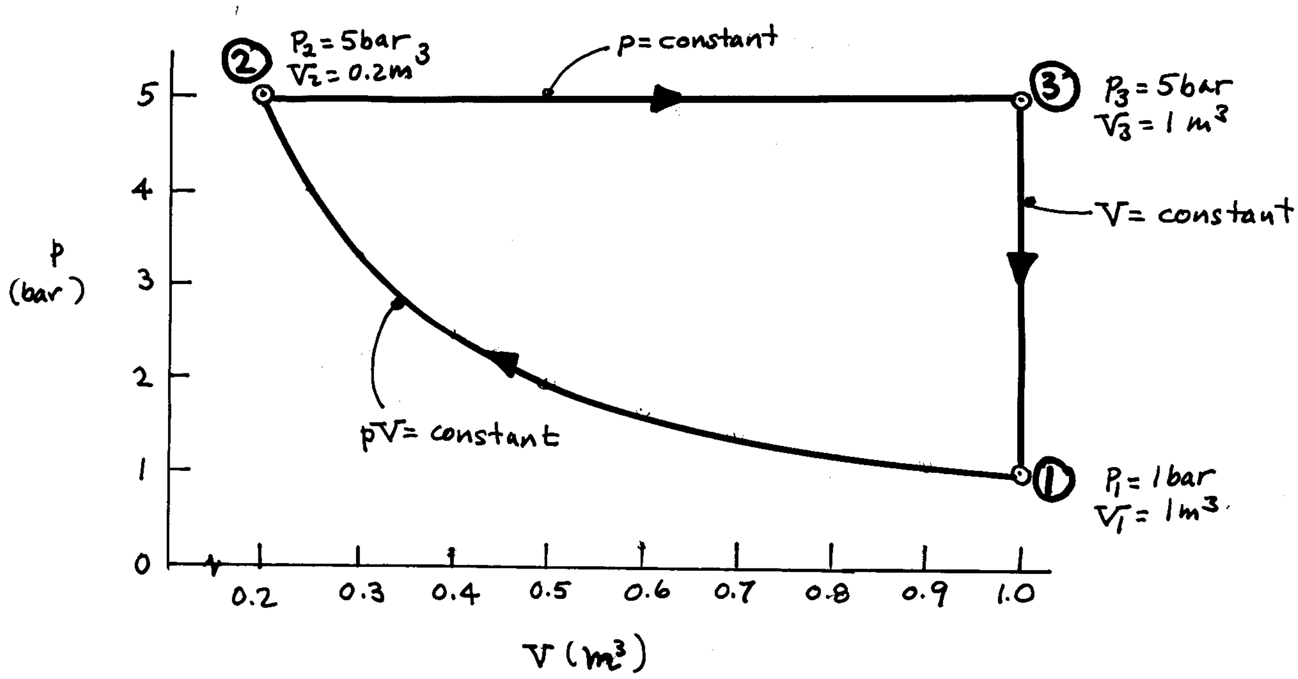
$$pV = \text{constant} = p_1 V_1 = (1\text{ bar})(1\text{ m}^3) = 1\text{ bar}\cdot\text{m}^3$$

Accordingly, on a pressure-volume plot process 1-2 is described by

$$p = \frac{1\text{ bar}\cdot\text{m}^3}{V}$$

In particular, when $V_2 = 0.2\text{ m}^3$, $p = 5\text{ bar}$.

The thermodynamic cycle takes the form



PROBLEM 2.27

Using Eq. 2.17

$$T(°F) = 1.8\, T(°C) + 32$$

(a) $\underline{\underline{T(°C) = 21}}$

$$T(°F) = (1.8)(21) + 32 = 69.8$$

$$T(°R) = T(°F) + 459.67 = 529.47$$

(b) $\underline{\underline{T(°C) = -17.78}}$

$$T(°F) = (1.8)(-17.78) + 32 = 0$$

$$T(°R) = 0 + 459.67 = 459.67$$

(c) $\underline{\underline{T(°C) = -50}}$

$$T(°F) = (1.8)(-50) + 32 = -58$$

$$T(°R) = -58 + 459.67 = 401.67$$

(d) $\underline{\underline{T(°C) = 300}}$

$$T(°F) = (1.8)(300) + 32 = 572$$

$$T(°R) = 572 + 459.67 = 1031.67$$

(e) $\underline{\underline{T(°C) = 100}}$

$$T(°F) = (1.8)(100) + 32 = 212$$

$$T(°R) = 212 + 459.67 = 671.67$$

(f) $\underline{\underline{T(°C) = -273.15}}$

$$T(°F) = (1.8)(-273.15) + 32 = -459.67$$

$$T(°R) = -459.67 + 459.67 = 0$$

PROBLEM 2.28

Using Eq. 2.17

$$T(^\circ C) = \frac{T(^\circ F)}{1.8} - \frac{32}{1.8}$$

$$= \frac{T(^\circ F)}{1.8} - 17.78$$

(a) $\underline{\underline{T(^\circ F) = 212}}$

$$T(^\circ C) = \frac{212}{1.8} - 17.78 = 100$$

$$T(K) = 100 + 273.15 = 373.15$$

(b) $\underline{\underline{T(^\circ F) = 68}}$

$$T(^\circ C) = \frac{68}{1.8} - 17.78 = 20$$

$$T(K) = 20 + 273.15 = 293.15$$

(c) $\underline{\underline{T(^\circ F) = 32}}$

$$T(^\circ C) = \frac{32}{1.8} - 17.78 = 0$$

$$T(K) = 0 + 273.15 = 273.15$$

(d) $\underline{\underline{T(^\circ F) = 0}}$

$$T(^\circ C) = \frac{0}{1.8} - 17.78 = -17.78$$

$$T(K) = -17.78 + 273.15 = 255.37$$

(e) $\underline{\underline{T(^\circ F) = -40}}$

$$T(^\circ C) = -\frac{40}{1.8} - 17.78 = -40$$

$$T(K) = -40 + 273.15 = 233.15$$

(f) $\underline{\underline{T(^\circ F) = -459.67}}$

$$T(^\circ C) = \frac{-459.67}{1.8} - 17.78 = -273.15$$

$$T(K) = 0$$

PROBLEM 2.29

$$T_2(°C) - T_1(°C) = [T_2(°C) + \cancel{273.15}] - [T_1(°C) + \cancel{273.15}] = T_2(K) - T_1(K)$$
$$T_2(°F) - T_1(°F) = [T_2(°F) + \cancel{459.67}] - [T_1(°F) + \cancel{459.67}] = T_2(°R) - T_1(°R)$$

PROBLEM 2.30

Using Eq. 2.17, $T(°F) = 1.8\,T(°C) + 32$. For $T(°F) = T(°C) = \hat{T}$

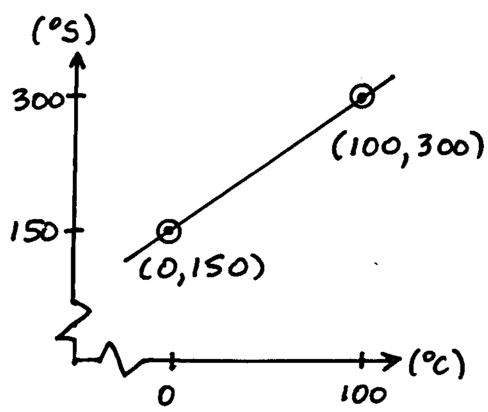
$$\hat{T} = 1.8\,\hat{T} + 32$$

Solving $\hat{T} = -40$ °F or °C $\longleftarrow$ $\hat{T}$

In K: $T(K) = T(°C) + 273.15 = -40 + 273.15 = 233.15$ $\longleftarrow$ $\hat{T}(K)$

In °R: $T(°R) = T(°F) + 459.67 = -40 + 459.67 = 419.67$ $\longleftarrow$ $\hat{T}(°R)$

PROBLEM 2.31



From the data, the relation can be expressed as

$$T(°S) = \left(\frac{300-150}{100-0}\right) T(°C) + 150\,°C$$
$$= 1.5\,T(°C) + 150$$

or $$T(°C) = \frac{T(°S) - 150}{1.5}$$

Using this relation

$T = 100°S \rightarrow -33.33\,°C$ $\longleftarrow$ $T(°C)$

$T = 400°S \rightarrow 166.67\,°C$ $\longleftarrow$ $T(°C)$

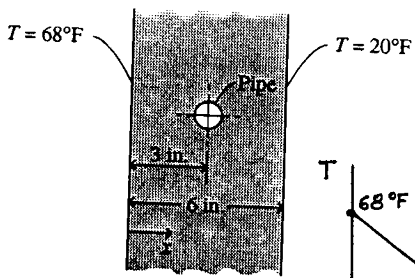
From Eq. 2.14

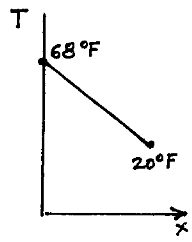
$$T(°S) = 1.5\,[T(K) - 273.15] + 150$$

Thus, the ratio of the size of the °S to the kelvin is

$1.5\,°S/K$ $\longleftarrow$ °S/K

PROBLEM 2.32





Since the temperature variation is linear

$$T = mx + b$$

where m is the slope and b is the value when $x = 0$.

Slope:

$$m = \left[\frac{20°F - 68°F}{6\text{ in.}}\right] = -8\ °F/\text{in.}$$

When $x = 0$, $T = 68°F$

Accordingly, the temperature variation through the wall is

$$T = -(8\ °F/\text{in.})\,x + 68°F$$

Checking the temperature at the pipe: $x = 3$ in.

$$T = -(8°F/\text{in.})(3\text{ in.}) + 68°F$$
$$= 44°F$$

There is no danger of freezing. ◄———

CHAPTER

3