Chapter 1 Solutions

Chapter 1 Problem Subject Areas

1.1–1.2 Applications of thermodynamics

1.3–1.14 Closed and open systems

1.14–1.31 Key concepts and definitions

1.32–1-55 Dimensions and units

1.56–1.69 Mathematics review

Problem 1.1 Conceptual Problem.
Definition of Thermodynamics:

> Thermodynamics is the science that deals with the relationship of heat and mechanical energy and conversion of one into the other.

There are many everyday thermodynamics applications. Some examples are included in Chapter 1. Other examples include:

Coaster brake on a bicycle converts mechanical energy of the moving wheel to frictional heating.

Refrigerator requires work input to transfers energy from the cold to the hot region.

The human body converts the energy from food to body heat and movement.

Problem 1.2 Conceptual Problem.

Device	Form of Energy Input	Form of Energy Output
Toaster	Electrical energy	Heat transfer from the hot metal strips
Air conditioner	Electrical energy	Heat transfer from cold to hot regions
Light bulb	Electrical energy	Heating of bulb by electrical resistance of the filament
Clothes iron	Electrical energy	Heat transfer
Refrigerator	Electrical energy	Heat transfer to kitchen

Problem 1.3 Conceptual Problem.

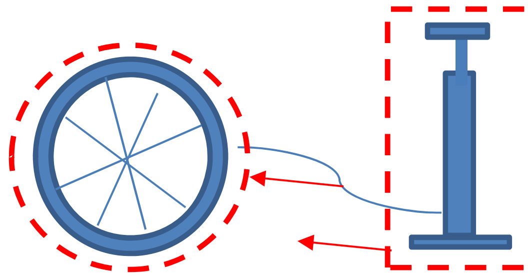
A closed and open system can have:

- a change of internal energy within the system
- heat transfer in or out of the system at the system boundary
- work transfer at the system boundary
- a change in the volume of the system

Only an open system will have mass entering or leaving the system.

Problem 1.4 Conceptual Problem.

Hand pump inflating a bicycle tire.

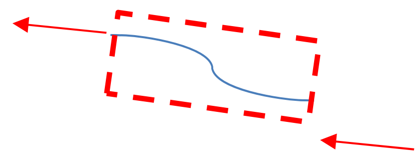


Closed Systems

- rubber tire (not including air)
- spokes of tire
- handle of pump

Open Systems

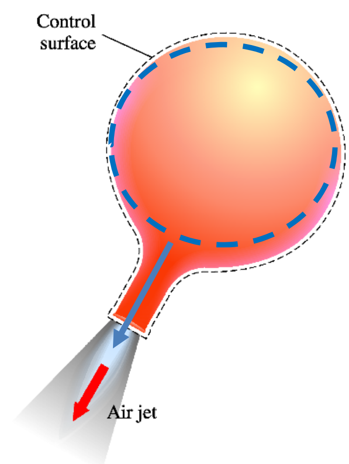
- open system around the tire the includes air entering the tire.
- Open system around pump that includes air entering and exiting the pump as the handle is pumped.
- Open system around the hose that include air flow in and out



Problem 1.5 Conceptual Problem.

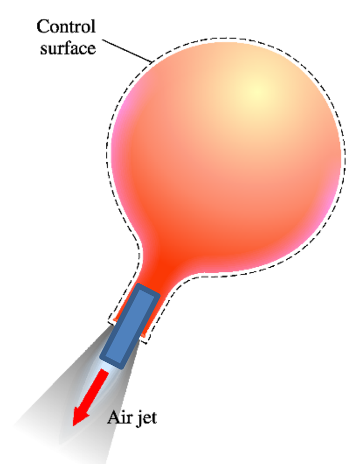
Using Figure 1.22,

An open system can be drawn to include only the air in the balloon and not the rubber balloon. As the balloon deflates, air will leave the new open system.



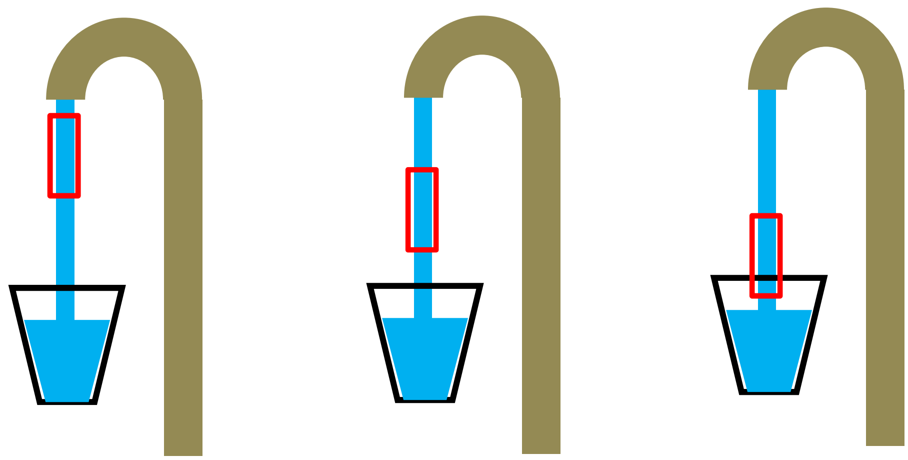
A closed system can be defined as the rubber balloon only without air.

A closed system can be defined as a fixed mass of air that moves from the inside to the outside of the balloon and can also change in volume.

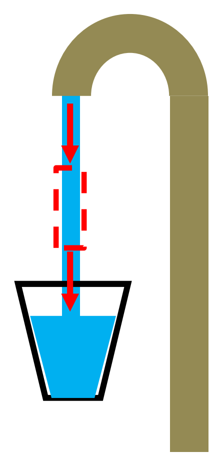


Problem 1.6 Conceptual Problem.

A closed system (shown as the solid red box) that includes the flow water would need to follow the defined mass of water as it falls into the glass.



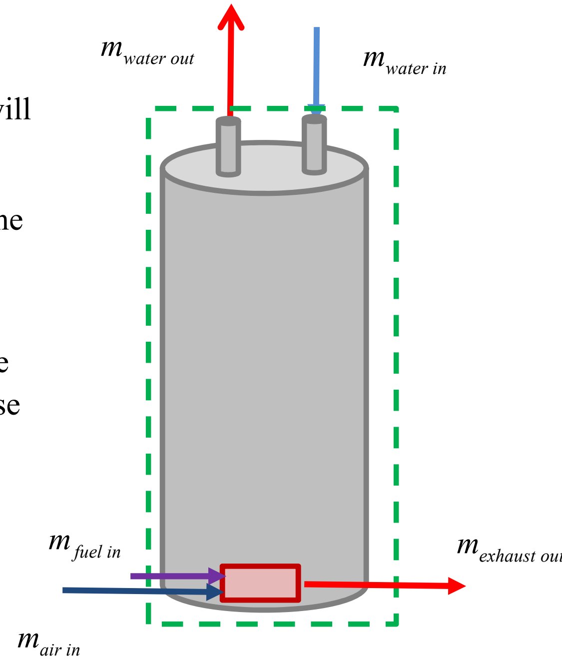
An open system would be stationary and water would enter and leave the open system.



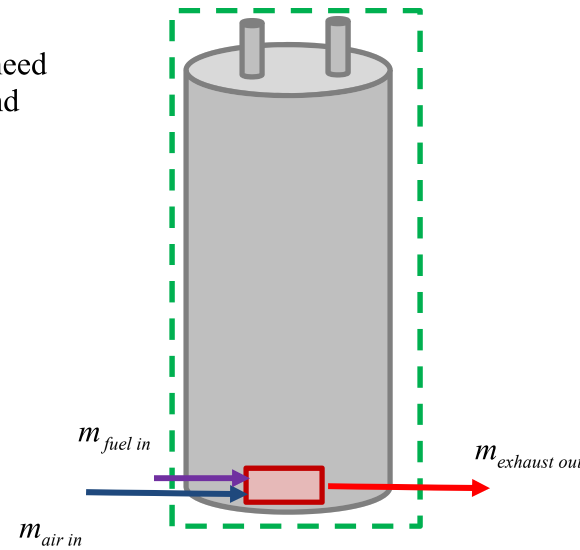
Problem 1.7 Conceptual Problem.

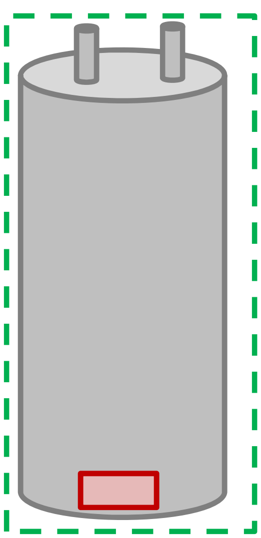
a. If water is being drawn for a shower, there will be a water flow in and out of the hot water heater. The gas-fired heater will also be operating and there will be gas and air into the heat and combustion gases out of the heater.

If the shower is running continuously and the gas-fired heater is running continuously, these terms can be written as mass flow rates, $\dot{m}$.



b. After the shower, no water is being drawn from the hot water heater but the water in the hot water heater will need to be heated so the gas-fired heater will be operating and there will be will be gas and air into the heat and combustion gases out of the heater.





c. When there is no demand for hot water and the water in the hot water heater has been heated, there will be no mass flow entering or leaving the hot water heater. This will now be a closed system.

Problem 1.8 Conceptual Problem.

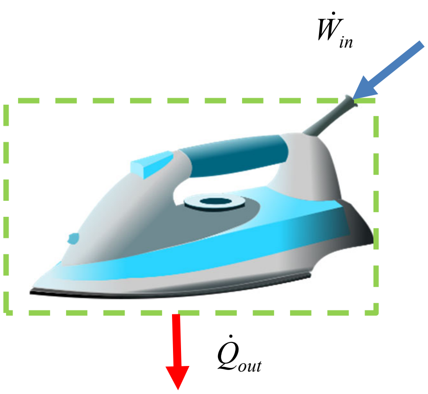
Yes, energy crosses the boundary of a thermodynamic system.

For a closed system, the energy transfer is in the form of heat or work ($P\mathcal{V}$ work, shaft work, or electrical work).

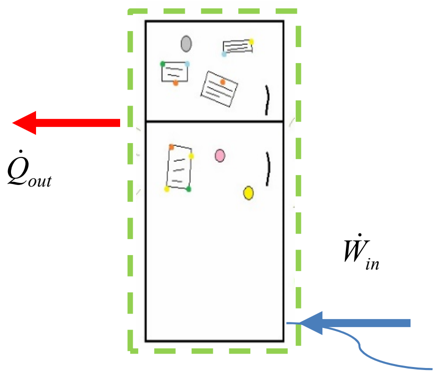
For an open system, the energy transfer can occur in the form of heat or work as occurs in the closed system. In addition, mass can enter and leave an open system and carry energy across the system boundary.

Problem 1.9 Conceptual Problem.

Clothes iron. Electrical work in, heat out.

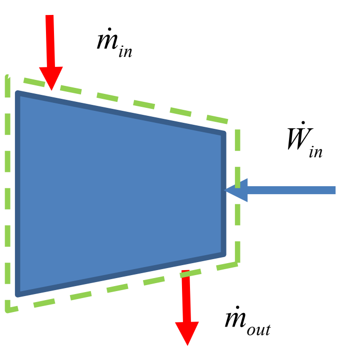


Refrigerator. Electrical work in, heat out.

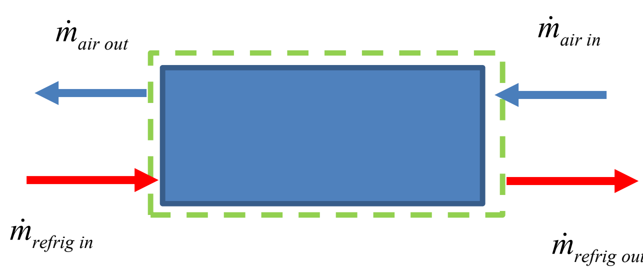


Problem 1.10 Conceptual Problem.

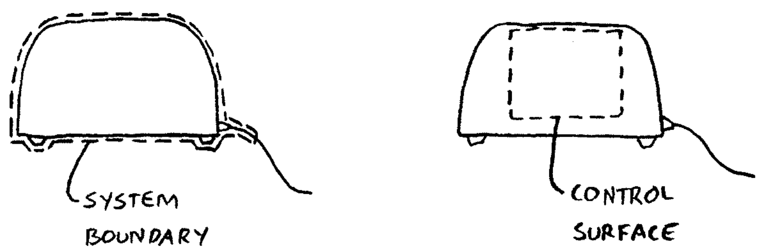
Compressor in an air conditioner
Refrigerant in and out. Shaft work in.



Heat exchanger (evaporator) in an air conditioner. Refrigerant in and out.
Air in and out.



Problem 1.11

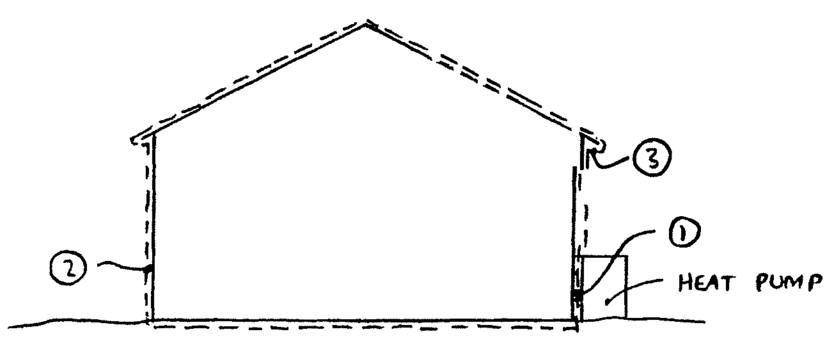


THE SYSTEM INCLUDES THE ENTIRE TOASTER. ENERGY COMES IN THROUGH THE POWER CORD AND LEAVES BY HEAT TRANSFER ACROSS THE SYSTEM BOUNDARY. THE CONTROL VOLUME CONSISTS OF THE AIR INSIDE THE TOASTER. ENERGY ENTERS AND EXITS THE FIXED CONTROL VOLUME BY HEAT TRANSFER ACROSS THE CONTROL SURFACE. AIR ENTERS AT BASE & EXITS AT TOP CARRYING MOISTURE FROM BREAD.

Problem 1.12

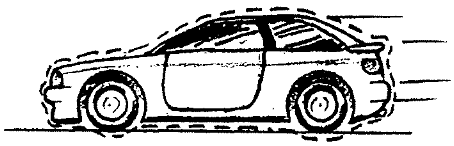
THE SYSTEM MUST BE DEFINED SUCH THAT NO MASS CROSSES THE SYSTEM BOUNDARY. THIS COULD BE DONE BY DEFINING THE SYSTEM AS ONLY THE COFFEE, OR ONLY THE MUG, OR THE MUG AND COFFEE TOGETHER, BUT EXCLUDING THE MOVING WATER VAPOR HOVERING OVER THE COFFEE.

Problem 1.13



1: REFRIGERANT ENTERS AND LEAVES THE HOUSE
2: AIR ENTERS AND LEAVES THROUGH OPEN OR LEAKING WINDOWS AND DOORS
3: AIR ENTERS AND LEAVES THROUGH VENTS

Problem 1.14



THIS IS A CONTROL VOLUME. MASS ENTERS THROUGH THE AIR INTAKE BEHIND THE GRILLE AND EXITS THROUGH THE TAILPIPE, AS WELL AS THROUGH THE CABIN VENTILATION SYSTEM. THIS BOUNDARY CAN BE CHANGED TO A SYSTEM BOUNDARY IF THIS AIRFLOW IS NEGLECTED. ADDITIONALLY, MANY OTHER SYSTEMS CAN BE CONSIDERED, FOR INSTANCE:

- A SLUG OF AIR MOVING THROUGH THE ENGINE
- THE FLUID IN THE COOLING SYSTEM
- THE DRIVE SYSTEM (TRANSMISSION, AXLES, TIRES, ETC.)

Problem 1.15

PROPERTY: A QUANTIFIABLE MACROSCOPIC CHARACTERISTIC OF A SYSTEM.

STATE: DEFINED BY THE VALUES OF ALL THE PROPERTIES OF THE SYSTEM.

PROCESS: WHEN A SYSTEM MOVES FROM ONE STATE TO ANOTHER.

EACH OF THESE THREE TERMS BUILDS ON THE PREVIOUS TERM. STATES ARE DEFINED BY PROPERTIES, AND PROCESSES ARE DEFINED BY STATES.

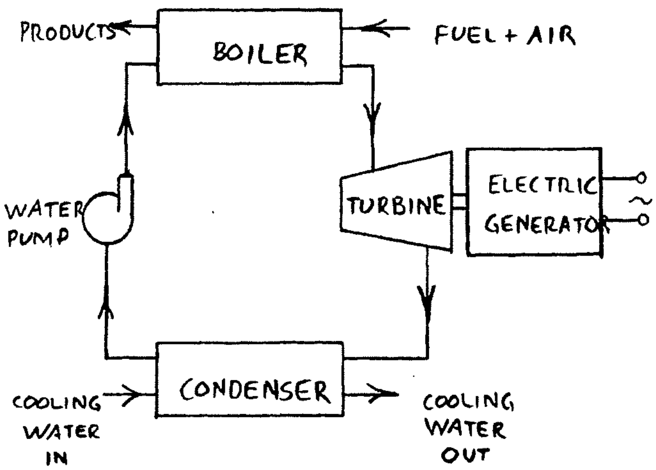
Problem 1.16

DEVICE	WORKING FLUID
AIR CONDITIONER	REFRIGERANT
INTERNAL COMBUSTION ENGINE	AIR (APPROXIMATION. IN REALITY THIS IS NOT A CYCLE SINCE THE AIR NEVER RETURNS TO ITS ORIGINAL STATE)
RERIGERATOR	REFRIGERANT
STEAM POWER PLANT	WATER

Problem 1.17

QUANTITY UNITS	MASS kg	PRECISION #	STANDARD #	SUBSTANDARD #	VALUE k$
INFLOW	520	0	0	0	0
PRODUCED	0	3000	5000	2000	30
OUTFLOW	295	1500	2000	2000	13.5
STORED	225	1500	3000	0	16.5
DESTROYED	0	0	0	0	0

Problem 1.18



- WATER PUMP: RAISES WATER PRESSURE TO CREATE FLOW THROUGH THE SYSTEM.
- BOILER: USES HEAT FROM BURNING FUEL TO CREATE WATER VAPOR.
- TURBINE: CONVERTS THERMAL ENERGY OF STEAM INTO MECHANICAL SHAFT WORK.
- GENERATOR: CONVERTS SHAFT WORK TO USABLE ELECTRICAL ENERGY.
- CONDENSER: USES COOL WATER TO EXTRACT HEAT FROM WORKING FLUID TO CONVERT IT BACK TO A LIQUID IN PREPARATION TO REPEAT THE CYCLE.

Problem 1.19

ACTIVE SOLAR HEATING INVOLVES A COMPLEX SYSTEM OF COMPONENTS IN ORDER TO HEAT WATER AND TO HEAT THE HOUSE. IN GENERAL, AN ACTIVE SYSTEM INVOLVES MOVING PARTS, WHILE A PASSIVE SYSTEM IS SIMPLER, WITHOUT MOVING PARTS OR CONTROLS. THE USE OF ONE TYPE OF SYSTEM OVER THE OTHER IS A MATTER OF THE HEATING DEMANDS OF THE USER.

Problem 1.20

THERMAL EQUILIBRIUM:
- UNIFORM TEMPERATURE
- SAME TEMPERATURE AS SURROUNDINGS

MECHANICAL EQUILIBRIUM:
- UNIFORM PRESSURE
- NO UNBALANCED FORCES

PHASE EQUILIBRIUM:
- AMOUNTS OF SUBSTANCES IN EACH PHASE REMAIN CONSTANT WITH TIME.

Problem 1.21 Conceptual Problem.

False. Thermodynamics equilibrium is defined as conditions when a system has a uniform temperature and is at the same temperature as its surroundings. Since a mixture of liquid and vapor state can occur at a uniform temperature, it can be in equilibrium.

Problem 1.22 Conceptual Problem.

True. A thermodynamic cycle is a series of processes that returns the working fluid to its original state so that the entire cycle of processes can repeat. Therefore, the temperature at the beginning and end of the cycle will be the same.

Problem 1.23 Conceptual Problem.

False. A thermodynamic cycle is a series of processes that returns the working fluid to its original state so that the entire cycle of processes can repeat. Therefore, all properties of the fluid must be the same at the beginning and end of the cycle.

Problem 1.24 Conceptual Problem.

True. If a closed system is in thermodynamics equilibrium with the surroundings, there is no mechanism for driving a change in the system properties.

Problem 1.25 Conceptual Problem.

False. Thermodynamics equilibrium is defined as conditions when a system has a uniform temperature and is at the same temperature as its surroundings. If there are hot and cold regions within the system, heat transfer will occur from the hot to cold region and cause a change in temperature with time and the system would not be in equilibrium.

Problem 1.26 Conceptual Problem.

False. In a quasi-equilibrium process, there are changes in the system properties (including possible changes in temperature and pressure) with time. These changes occur sufficiently slowly so that we can assume that the entire system is at a uniform temperature and pressure at any given time.

Problem 1.27 Conceptual Problem.

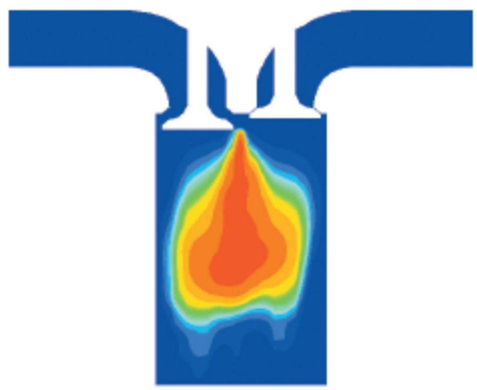
True. In a quasi-equilibrium process, there can be changes and the changes can be large. The quasi-equilibrium approximation only specifies that the changes occur sufficiently slowly so that we can assume that the entire system is at a uniform temperature and pressure at any given time.

Problem 1.28 Conceptual Problem.

True. In a quasi-equilibrium process, the changes occur sufficiently slowly so that we can assume that the entire system is at a uniform temperature and pressure at any given time. We can think of these changes as occurring as occurring in small differential (infinitesimal) increments from thermodynamic equilibrium. Added together (integrated) these differential changes can result in a large change in pressure or temperature during the entire process.

Problem 1.29 Conceptual Problem.

In a rapid expansion of a gas, there will be significant differences in the pressure and temperature at different locations in the system. For example, see the figure in Example 7.5 showing the composition of the fuel air mixture in an internal combustion engine. At this instant in the air intake stroke, the composition is no uniform across the engine.



During the intake stroke of a real spark-ignition engine, fresh fuel and air enter the cylinder and mix with the residual gases. Image courtesy of Eugene Kung and Daniel Haworth.

Problem 1.30 Conceptual Problem.

No, the system is not in equilibrium since the temperature is not uniform across the system, including the system boundary. The process is also not quasi-equilibrium since the process needs to occur slow enough so that the temperature across the system is (nearly) uniform with only a small differential change in temperature causing the slow process to occur.

Problem 1.31 Conceptual Problem.

Yes, ice and liquid water can occur as a mixture at a uniform temperature. If heat transfer occurs slowing into the system, the ice can slowly melt at constant temperature and undergo a quasi-equilibrium process.

Problem 1.32   Open-Ended Problem.

There are many possible examples for this question. One can search the internet for “disaster due to units conversions” to see lists. One example is the failed attempt to land on Mars in 1999 due to an error in the units conversion. Other examples are the wrong axle size in rollercoaster at Tokyo Disneyland in 2003 and an airplane running out of fuel in 1983.

Now add things

Problem 1.33

WEIGHT IN NEWTONS = WEIGHT IN POUNDS × $\left(\frac{4.44822 \text{ N}}{1 \text{ lbf}}\right)$

$$\underline{160 \text{ lbf}} = 160 \text{ lbf}\left(\frac{4.44822 \text{ N}}{1 \text{ lbf}}\right) = \underline{712 \text{ N}}$$

MASS IN lbm IS NUMERICALLY EQUAL TO WEIGHT IN lbf ASSUMING THE ACCELERATION DUE TO GRAVITY IS 1g. $\underline{160 \text{ lbm}}$

$$W = mg \Rightarrow m = \frac{W}{g} \qquad m_{slug} = \frac{160 \text{ lbm}}{32.17 \frac{ft}{s^2}} = \underline{4.97 \text{ slug}}$$

$$m_{kg} = \frac{712 \text{ N}}{9.81 \frac{m}{s^2}} = \underline{72.6 \text{ kg}}$$

Problem 1.34

MASSES DO NOT CHANGE WITH GRAVITATIONAL FIELD, SO IT IS STILL

$\underline{4.97 \text{ slug}} = \underline{72.6 \text{ kg}} = \underline{160 \text{ lbm}}$

$$F = ma \qquad F_N = (72.6 \text{ kg})(3.71 \text{ m/s}^2) = \underline{269 \text{ N}}$$

$$F_{lbf} = (4.97 \text{ slug})(3.71 \text{ m/s}^2)(3.28084 \text{ ft/m}) = \underline{60.5 \text{ lbf}}$$

Problem 1.35

$$\left(86{,}000 \frac{\text{BTU}}{\text{hr}}\right)\left(\frac{63.825 \text{ kJ}}{\text{BTU}}\right)\left(\frac{1 \text{ hr}}{3600 \text{ s}}\right) = \boxed{25.2 \text{ kW}}$$

$$(25.2 \text{ kW})\left(\frac{1000 \text{ W}}{\text{kW}}\right)\left(\frac{1 \text{ BULB}}{100 \text{ W}}\right) = \boxed{252 \text{ BULBS}}$$

Problem 1.36

Known: Volume, power, torque, distance, speed (US units)

Find: Same quantities in SI units

Analysis: Apply conversion factors at front of book

A. $389\,in^3 = ?\ m^3$

$$389\,(in)^3\left[\frac{1\,(m)^3}{(39.370)^3\,in^3}\right] = 0.006375\,m^3$$

or $$0.006375\,m^3\left[\frac{1000\,\ell}{m^3}\right] = 6.375\,\ell$$

B. $348\,HP = ?\ W$

$$348\,HP\left[\frac{1\,W}{1.341\cdot 10^{-3}\,HP}\right] = 259{,}500\,W$$

or $259.5\,kW$

C. $428\,lb_f\text{-}ft = ?\ N\text{-}m$

$$428\,lb_f\text{-}ft\left[\frac{1\,m}{3.2808\,ft}\right]\left[\frac{1\,N}{0.224809\,lb_f}\right]$$

$$= 580\,N\text{-}m$$

Problem 1.36, cont.

D. 1/4 mi = ? km

$$0.25\,mi\left[\frac{5280\,ft}{mi}\right]\left[\frac{1\,m}{3.2808\,ft}\right]\left[\frac{1\,km}{1000\,m}\right]$$

$$= 0.402\,km$$

E. 95 mph = ? m/s

$$95\,\frac{mi}{hr}\left[\frac{5280\,ft}{mi}\right]\left[\frac{1\,m}{3.2808\,ft}\right]\left[\frac{1\,hr}{3600\,s}\right]$$

$$= 42.5\,m/s$$

or, more directly,

$$95\,mph\left[\frac{1\,m/s}{2.237\,mph}\right] = 42.5\,m/s$$

COMMENTS: This problem illustrates the use of the conversion factors provided inside the front cover and the application of the factor-label method to keep track of unit cancellations. Note the use of square brackets [—] to denote unity (≡ 1). A modern muscle car is the Chrysler/Dodge Viper GTS having the following specs.: 7.99 ℓ, 450 HP, 490 lbf-ft, and 12.2 s @ 118 mph.

Problem 1.37

Known: SO_2 emission factor in U.S. units

Find: Factor in g/kJ

Analysis: Apply conversion factors at front of book

$$0.80 \frac{lb_m}{10^6 \, BTU} \left[\frac{kg}{2.2046 \, lb_m}\right] \left[\frac{1000 g}{kg}\right] \left[\frac{0.9478 \, BTU}{kJ}\right]$$

$$= 3.44 \cdot 10^{-4} \frac{g}{kW} \quad \text{or} \quad 0.344 \, g/MW$$

Comment: In the power generation community, 10^6 BTU is frequently denoted MMBTU, i.e., a thousand Thousand BTUs. This use of "M" can result in confusion.

Problem 1.38

Known: NAAQS for Pb in $\mu g/m^3$

Find: Pb standard in lb_m/ft^3

Analysis:

$$1.5 \frac{\mu g}{m^3} \left[\frac{g}{10^6 \mu g}\right]\left[\frac{2.2046\ lb_m}{10^3 g}\right]\left[\frac{1 m^3}{(3.2808)^3 ft^3}\right]$$

$$= 9.36 \cdot 10^{-11}\ lb_m/ft^3$$

Comment: Clearly, $\mu g/m^3$ is more convenient units than the lb_m/ft^3 units.

Problem 1.39

Known: Mass of moon rocks, g_{moon}, g_{Earth}

Find: Weight of moon rocks on earth & moon; mass in lb_m units

Analysis: Apply $W = mg$:

a) Moon

$$W_M = 111\ kg\ 1.62\ \frac{m}{s^2}\left[\frac{1N}{kg-m/s^2}\right] = 179.8\ N$$

$$W_m = 178.9\ N\left[\frac{0.224809\ lb_f}{N}\right] = 40.4\ lb_f$$

b) $$W_E = 111\ kg\ 9.807\ \frac{m}{s^2}\left[\frac{1N}{kg-m/s^2}\right] = 1088\ N$$

$$= 244.7\ lb_f$$

c) $$m = \frac{F}{g_E} = \left\{\frac{244.7\ lb_f}{9.807\ \frac{m}{s^2}\left[\frac{3.2808\ ft}{m}\right]}\right\}$$

$$\cdot\left[\frac{32.174\ lb_m}{\frac{lb_f}{ft/s^2}}\right] = 244.7\ lb_m$$

Comment: The formal determination of the mass in lb_m agrees with our knowledge that, on Earth, lb_m and lb_f are numerically equal.

Problem 1.40

pi = 3.14159

Location	Latitude (deg)	Altitude (m)	g (m/s^2)	Mass (kg)	Weight (N)	Weight (lb_f)
Kilimanjaro	3.07	5895	9.76231	54	527.2	118.51
Aconcagua	32	6962	9.77335	54	527.8	118.65
Denali	63	6194	9.80227	54	529.3	119.00
Sea level	45	0	9.80616	54	529.5	119.04

Comment: Note that the latitude must be expressed in radians to evaluate sin(theta).

Problem 1.41

Known:

Location	g (m/s²)
Jupiter	23.12
Pluto	0.72
Sun	273.98

Find: Your weight (N, lb_f)

Assume: $M = 140\ lb_m$ or $63.5\ kg$

Analysis:

Jupiter: $W = mg$

$$= 63.5\ kg\ 23.12\ \frac{m}{s^2}\left[\frac{1\ N}{kg\text{-}m/s^2}\right]$$

$$= 1468.1\ N$$

or $1468.1\ N\left[\frac{0.224809\ lb_f}{N}\right] = 330\ lb_f$

Pluto: $W = 63.5(0.72) = 45.7\ N$

or $= 10.3\ lb_f$

Sun: $W = 63.5\ (273.98) = 17{,}398\ N$

or $3911\ lb_f$!

Comment: At the solar surface, molecules would dissociate/ionize.

Problem 1.42

Known: $\dot{E}_{in} = 4845 \cdot 10^6$ BTU/hr (coal)
$\dot{E}_{out} = 500$ MW (electricity)

Find: Overall powerplant efficiency

Analysis: $\eta \equiv \dfrac{\dot{E}_{out}}{\dot{E}_{in}}$

$$\eta = \frac{500 \cdot 10^6 \text{ W}}{4845 \cdot 10^6 \frac{\text{BTU}}{\text{hr}} \left[\frac{1 \text{ W}}{3.41214 \text{ BTU/hr}}\right]}$$

$= 0.352$ (dim'less)

Comments: About 35% of the energy stored in the coal is converted to electricity – the useful output. The bulk of the remainder is rejected as heat to the surroundings and as thermal energy carried with the exhaust stack gases.

Problem 1.43

Known: Two measures of pressure: Pa and psi

Find: Conversion factor

Analysis:

$$1\ \text{Pa}\left[\frac{\text{N/m}^2}{1\ \text{Pa}}\right]\left[\frac{0.224809\ \text{lb}_f}{\text{N}}\right]\left[\frac{1\ \text{m}^2}{(39.370)^2\ \text{in}^2}\right]$$

$$= 1.4504\cdot 10^{-4}\ \frac{\text{lb}_f}{\text{in}} \text{ or psi}$$

Comment: This value agrees with the conversion factor presented at the front of the book.

Problem 1.44

Known: SSME specifications (U.S. customary)

Find: specifications in SI units

Analysis: Apply various conversion factors -

Thrust: $408{,}750\ lbf \left[\frac{1\ N}{0.224809\ lbf}\right] = 1.8182 \cdot 10^6\ N$

$512{,}300\ lbf \left[\frac{1\ N}{0.224809\ lbf}\right] = 2.2788 \cdot 10^6\ N$

Pressures:

$6{,}872\ psi \left[\frac{1\ Pa}{1.4504 \cdot 10^{-4}\ psi}\right] = 4.738 \cdot 10^7\ Pa$

or 47.38 MPa

$7{,}936\ psi \left[\quad\right] = 54.71\ MPa$

$3{,}277\ psi \left[\quad\right] = 22.59\ MPa$

Flowrates:

$160\ \frac{lbm}{s} \left[\frac{1\ kg}{2.2046\ lbm}\right] = 72.6\ kg/s$

$970\ \frac{lbm}{s} \left[\quad\right] = 440\ kg/s$

Problem 1.44, cont.

Power:

$$74{,}928\ hp \left[\frac{W}{1.341\cdot 10^{-3}\ hp}\right] = 5.58747\cdot 10^{7}\ W$$

or 55.8747 MW

$$28{,}229\ hp \left[\quad\quad\right] = 2.10507\cdot 10^{7}\ W$$

or 21.0507 MW

Weight:

$$7000\ lb_f \left[\frac{1\ N}{0.224809\ lb_f}\right] = 31{,}140\ N$$

Dimensions:

$$14\ ft \left[\frac{1\ m}{3.2808\ ft}\right] = 4.27\ m$$

$$7.5\ ft \left[\quad\quad\right] = 2.29\ m$$

Comments: This problem presents many quantities associated with thermal-fluids engineering and offers a lot of practice with units conversion.

Note the huge values of performance measures for this "small" engine.

Problem 1.45

$F = ma$, OR IN THIS CASE $W = mg$

FOR NUMERICALLY EQUAL WEIGHT (N) AND MASS (kg), $\frac{W}{m} = 1$

$$\boxed{\frac{W}{m} = g = 1\ m/s^2}$$

PROBLEM 1.42

$F = ma \Rightarrow 200\ lbf = m(50\ ft/s) \Rightarrow m = 4\ SLUG = \boxed{129\ lbm}$

PROBLEM 1.43

$F = ma \Rightarrow 1000N = m(15\ m/s^2) \Rightarrow m = \boxed{66.7\ kg}$

PROBLEM 1.44

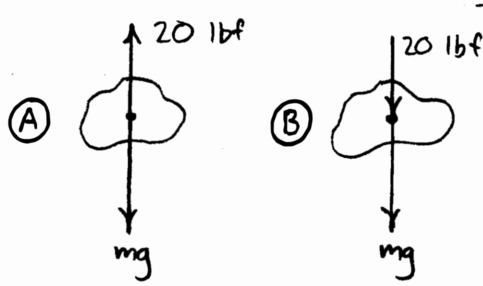
$50\ lbf \left(\frac{4.44822\ N}{lbf}\right) = 222.4\ N$

$F = ma \Rightarrow 222.4\ N = (50\ kg)\ a \Rightarrow \boxed{a = 4.45\ m/s^2}$

PROBLEM 1.45

$F = ma = (92.99\ kg)(1.676\ m/s^2) \Rightarrow \boxed{F = 156\ N}$

PROBLEM 1.46



$5\ lbm = 0.1554\ SLUG$

$\Sigma F = ma \Rightarrow \frac{\Sigma F}{m} = a = \frac{mg \pm 20\ lbf}{m} = a$

(A): $\frac{(0.1554)(30) - 20}{0.1554} = \boxed{a_A = 98.7\ \frac{ft}{s^2}\ UP}$

(B): $\frac{(0.1554)(30) + 20}{0.1554} = \boxed{a_B = 159\ \frac{ft}{s^2}\ DOWN}$

Problem 1.46

DENSITY: $120 \frac{lbm}{ft^3}\left[\frac{0.45359\ kg}{lbm}\right]\left[\frac{1\ ft^3}{0.02832\ m^3}\right] = \boxed{1920\ \frac{kg}{m^3}}$

THERMAL CONDUCTIVITY: $170 \frac{BTU}{hr \cdot ft \cdot F}\left[\frac{1\ J}{9.47817 \times 10^{-4}\ BTU}\right]\left[\frac{1\ ft}{0.3048\ m}\right]\left[\frac{1\ F}{5/9\ K}\right]\left[\frac{1\ hr}{3600\ s}\right]\left[\frac{1\ W}{1\ J/s}\right] =$

$= \boxed{294\ \frac{W}{m \cdot K}}$

CONVECTIVE HEAT TRANSFER COEFFICIENT: $211 \frac{BTU}{hr \cdot ft^2 \cdot F}\left[\frac{1\ J}{9.47817 \times 10^{-4}\ BTU}\right]\left[\frac{1\ ft^2}{0.0929\ m^2}\right]\left[\frac{1\ F}{5/9\ K}\right]\left[\frac{1\ hr}{3600\ s}\right]\left[\frac{1\ W}{1\ J/s}\right] =$

$= \boxed{1200\ \frac{W}{m^2 \cdot K}}$

SPECIFIC HEAT: $175 \frac{BTU}{lbm \cdot F}\left[\frac{1\ J/kg \cdot K}{2.3886 \times 10^{-4}\ BTU/lbm \cdot F}\right] = 732{,}646 \frac{J}{kg \cdot K}$ OR $\boxed{733\ \frac{kJ}{kg \cdot K}}$

VISCOSITY: $20\ \text{CENTIPOISE}\left[\frac{1 \times 10^{-3}\ Pa \cdot s}{\text{CENTIPOISE}}\right] = \boxed{2 \times 10^{-2}\ Pa \cdot s}$

VISCOSITY: $77 \frac{lbf \cdot s}{ft^2}\left[\frac{1\ N}{0.22481\ lbf}\right]\left[\frac{10.76391\ ft^2}{1\ m^2}\right]\left[\frac{1\ Pa}{1\ N/m^2}\right] = \boxed{3690\ Pa \cdot s}$

KINEMATIC VISCOSITY: $3.0 \frac{ft^2}{s}\left[\frac{1\ m^2}{10.76391\ ft^2}\right] = \boxed{0.279\ \frac{m^2}{s}}$

STEFAN-BOLTZMANN CONSTANT: $0.1713 \times 10^{-8} \frac{BTU}{ft^2 \cdot hr \cdot R^4}\left[\frac{1\ J}{9.478 \times 10^{-4}\ BTU}\right]\left[\frac{1\ ft^2}{0.0929\ m^2}\right]\left[\frac{1\ hr}{3600\ s}\right]\left[\frac{1\ R}{5/9\ K}\right]^4\left[\frac{1\ W}{1\ J/s}\right] =$

$= \boxed{5.67 \times 10^{-8}\ \frac{W}{m^2 \cdot K^4}}$

ACCELERATION: $12.0\ ft/s^2\left[\frac{1\ m}{3.28084\ ft}\right] = \boxed{3.66\ m/s^2}$

Problem 1.47

Conversion factors: 1 calorie = 4184 J given in problem

1 J = 9.478×10^{-4} Btu listed in textbook inside front cover

39.370 in = 1 m, 1 m^3 = 1000 liters

A. Soft drink. Note that fluid ounces are given in this problem

$$\text{energy density} = \left(\frac{120 \text{ calories}}{12 \text{ fl oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{1 \text{ fl oz.}}{1.805 \text{ in}^3}\right)\left(\frac{39.370 \text{ in}}{1 \text{ m}}\right)^3\left(\frac{1 \text{ m}^3}{1000 \text{ liters}}\right)\left(\frac{1 \text{ liter}}{1.1 \text{ kg}}\right)\left(\frac{1 \text{ kg}}{2.2046 \text{ lbm}}\right)$$

$$= 552.8 \text{ Btu/lbm}$$

B. Bagel. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{290 \text{ calories}}{3.8 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$

$$= 4840.9 \text{ Btu/lbm}$$

C. Honey

$$\text{energy density} = \left(\frac{64 \text{ calories}}{21.3 \text{ g}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{1000 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ kg}}{2.2046 \text{ lbm}}\right)$$

$$= 5404.8 \text{ Btu/lbm}$$

Gasoline has an $\text{energy density} = 20{,}000 \text{ Btu/lbm}$

All of these foods have a lower energy density than gasoline. The soft drink has the lowest energy density that is only 1/36 of the energy density of gasoline.

Problem 1.48

Conversion factors: 1 calorie = 4184 J given in problem

1 J = 9.478×10^{-4} Btu listed in textbook inside front cover

39.370 in = 1 m, 1 m^3 = 1000 liters

A. Bread. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{140 \text{ calories}}{2 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$

$$\boxed{= 4441.5 \text{ Btu/lbm}}$$

B. Hostess Twinkie. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{290 \text{ calories}}{1.5 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$

$$\boxed{= 12,267 \text{ Btu/lbm}}$$

C. Steak. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{414 \text{ calories}}{8 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$

$$\boxed{= 3283.5 \text{ Btu/lbm}}$$

D. Green Beans. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{44 \text{ calories}}{4.4 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$

$$\boxed{= 634.5 \text{ Btu/lbm}}$$

Gasoline has an $\text{energy density} = 20{,}000 \text{ Btu/lbm}$

All of these foods have a lower energy density than gasoline. The green beans has the lowest energy density that is only 1/31 of the energy density of gasoline.

Problem 1.49

Conversion factors: 1 calorie = 4184 J given in problem

1 J = 9.478×10^{-4} Btu listed in textbook inside front cover

39.370 in = 1 m, 1 m^3 = 1000 liters

A. Ice Cream. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{273 \text{ calories}}{4.7 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$
$$= 3685.5 \text{ Btu/lbm}$$

B. Pear. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{133 \text{ calories}}{8.1 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$
$$= 1041.8 \text{ Btu/lbm}$$

C. Cottage Cheese. Note that ounces of weight are given in this problem.

$$\text{energy density} = \left(\frac{26 \text{ calories}}{1 \text{ oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lbm}}\right)$$
$$= 1649.7 \text{ Btu/lbm}$$

A. Cranberry Juice. Note that fluid ounces are given in this problem

energy density

$$= \left(\frac{45 \text{ calories}}{8 \text{ fl oz.}}\right)\left(\frac{4184 \text{ J}}{1 \text{ calorie}}\right)\left(\frac{9.478e^{-4} \text{ Btu}}{1 \text{ J}}\right)\left(\frac{1 \text{ fl oz.}}{1.805 \text{ in}^3}\right)\left(\frac{39.370 \text{ in}}{1 \text{ m}}\right)^3\left(\frac{1 \text{ m}^3}{1000 \text{ liters}}\right)\left(\frac{1 \text{ liter}}{1.1 \text{ kg}}\right)\left(\frac{1 \text{ kg}}{2.2046 \text{ lbm}}\right)$$
$$= 325.8 \text{ Btu/lbm}$$

Gasoline has an energy density=20,000 Btu/lbm

All of these foods have a lower energy density than gasoline. The jiuce has the lowest energy density that is only 1/61 of the energy density of gasoline.

Problem 1.50

Conversions. Energy rate: 1 ton=3.517 kW

$$\text{cost} = (1\text{ ton})\left(\frac{3.517\text{ kW}}{1\text{ ton}}\right)(2\text{ hours})\left(\frac{12.2¢}{1\text{ kW-hr}}\right) = \boxed{85.8¢}$$

Problem 1.51

Conversions. Energy rate: $1\text{ J} = 9.478\times10^{-4}\text{ Btu}$ listed in textbook inside front cover

This can also be written as: 1 kJ = 0.9478 Btu

$$\frac{\#\text{ tons}}{\text{week}} = (50{,}000\text{ homes})\left(750\frac{\text{kW-hr}}{\text{month}}\right)\left(\frac{3600\text{ s}}{1\text{ hr}}\right)\left(\frac{1\text{ month}}{4\text{ weeks}}\right)\left(\frac{0.9478\text{ Btu}}{1\text{ kJ}}\right)\left(\frac{1\text{ lbm}}{13000\text{ Btu}}\right)\left(\frac{1}{0.32}\right)\left(\frac{1\text{ ton}}{2000\text{ lbm}}\right)$$

$$\boxed{= 3845\text{ tons}}$$

If one dump truck carries 25 tons, there must be 154 trucks to deliver this coal!

Problem 1.52

Conversions. Energy rate: 1 food calorie = 4184 J given in problem

$$\text{energy rate} = \frac{\text{energy}}{\text{time}} = \frac{10\text{ calories}}{1\text{ minute}}\left(\frac{4184\text{ J}}{1\text{ calorie}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right) = \boxed{697.3\text{ W}}$$

This power will light almost **7 light bulbs.**

Problem 1.53

Conversions. Energy rate: 1 food calorie = 4184 J given in problem

$$\text{energy} = \frac{\text{energy}}{\text{time}}\times\text{time} = \frac{11\text{ calories}}{1\text{ minute}}(30\text{ minutes})\left(\frac{4184\text{ J}}{1\text{ calorie}}\right)\left(\frac{9.478\times10^{-4}\text{ Btu}}{1\text{ J}}\right) = \boxed{1308.6\text{ Btu}}$$

$$\text{weight of gas} = (1308.6\text{ Btu})\left(\frac{1\text{ lbm}}{20{,}000\text{ Btu}}\right)\left(\frac{16\text{ oz}}{1\text{ lbm}}\right) = \boxed{1.047\text{ oz.}}$$

Problem 1.54

Conversions. Energy rate: 1 food calorie = 4184 J given in problem

$$\text{energy rate}=\frac{\text{energy}}{\text{time}}=\frac{120\text{ calories}}{60\text{ minute}}\left(\frac{4184\text{ J}}{1\text{ calorie}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)\boxed{=139.5\text{ W}}$$

This power will light **1.3 light bulbs.**

Problem 1.55

Conversions. Energy rate: 1 food calorie = 4184 J given in problem

$$\text{energy}=(428\text{ calories})\left(\frac{4184\text{ J}}{1\text{ calorie}}\right)=1790.8\text{ kJ}$$

$$\text{time}=\frac{\text{energy}}{\text{power}}=\frac{1790.8\text{ kJ}}{500\text{ W}}\boxed{=59.69\text{ minutes}}$$

The rate of energy used to play tennis is nearly the same as to operate the blow dryer.

Problem 1.56

Create an interpolation table as shown in Tutorial 1.

x	y
0.1	5.81
0.14	
0.2	2.96

$$y=y_1+(y_2-y_1)\frac{(x-x_1)}{(x_2-x_1)}=5.81+(5.81-2.96)\frac{(0.14-0.1)}{(0.2-0.1)}\boxed{=4.67}$$

The interpolated property should be rounded to the same decimal place as the given values.

Problem 1.57

Create an interpolation table as shown in Tutorial 1.

T	h
350	476.4
357	
360	486.5

$$h = h_1 + (h_2 - h_1)\frac{(T - T_1)}{(T_2 - T_1)} = 476.4 + (486.5 - 476.4)\frac{(357 - 350)}{(360 - 350)} = \boxed{483.5}$$

The interpolated property should be rounded to the same decimal place as the tabulated values.

Problem 1.58

Create an interpolation table as shown in Tutorial 1.

P	T
4.10	524.97
4.13	
4.20	526.41

$$T = T_1 + (T_2 - T_1)\frac{(P - P_1)}{(P_2 - P_1)} = 524.97 + (526.41 - 524.97)\frac{(4.13 - 4.1)}{(4.2 - 4.1)} = \boxed{525.40}$$

The interpolated property should be rounded to the same decimal place as the tabulated values.

Problem 1.59

Create an interpolation table as shown in Tutorial 1.

P	v
0.50	0.3748
0.56	
0.60	0.3156

$$v = v_1 + (v_2 - v_1)\frac{(P - P_1)}{(P_2 - P_1)} = 0.3748 + (0.3156 - 0.3748)\frac{(0.56 - 0.5)}{(0.6 - 0.5)} = \boxed{0.3393}$$

The interpolated property should be rounded to the same decimal place as the tabulated values.

Problem 1.60

Create an interpolation table as shown in Tutorial 1.

T	ρ
320	0.1524
333	
340	0.1434

$$\rho = \rho_1 + (\rho_2 - \rho_1)\frac{(T - T_1)}{(T_2 - T_1)} = 0.1524 + (0.1434 - 0.1524)\frac{(333 - 320)}{(340 - 320)} = \boxed{0.1466}$$

The interpolated property should be rounded to the same decimal place as the tabulated values.

Problem 1.61

Create an interpolation table as shown in Tutorial 1.

u	s
2461.2	7.8442
2462.0	
2463.5	7.8167

$$s = s_1 + (s_2 - s_1)\frac{(u-u_1)}{(u_2-u_1)} = 7.8442 + (7.8167 - 7.8442)\frac{(2462.0 - 2461.2)}{(2463.5 - 2461.2)} = \boxed{7.8346}$$

The interpolated property should be rounded to the same decimal place as the tabulated values.

Problem 1.62

$$\frac{dy}{dx} = \frac{d}{dx}\left(a + bx + cx^3\right) \boxed{= b + 3cx^2}$$

Problem 1.63

$$\frac{dP}{dT} = \frac{d}{dT}\left(a\ln T + bT^{-1}\right) \boxed{= aT^{-1} - bT^{-2}}$$

Problem 1.64

$$\frac{dz}{dT} = \frac{d}{dT}\left(-0.29T + 26.3T^2 - 10.61T^3 + 1.56T^4 - 0.16T^{-1} - 18.3\right)$$

$$= -0.29 + 26.3T - 3(10.61)T^2 + 4(1.56)T^3 + 0.16T^{-2}$$

$$\boxed{= -0.29 + 26.3T - 31.83T^2 + 6.24T^3 + 0.16T^{-2}}$$

The coefficients in this problem are for the enthalpy of methane. Taking the derivative with respect to temperature will give the specific heat at constant pressure at this temperature.

Problem 1.65

$$\frac{dT}{dP} = \frac{d}{dP}\left(32.4P^{-0.5} - 12.8P^{0.5}\right)$$
$$= -0.5(32.4)P^{-1.5} - 0.5(12.8)P^{-0.5} = \boxed{-16.2P^{-1.5} - 6.4P^{-0.5}}$$

Problem 1.66

$$\int\left(19.86 - 597x^{-0.5} + 7500x^{-1}\right)dx = 19.86x + \frac{597}{0.5}x^{0.5} + 7500\ln x$$
$$\boxed{= 19.86x + 1194x^{0.5} + 7500\ln x}$$

Problem 1.67

Solve for the function of $z(y)$ **:** $z = \sqrt{y/11.6}$

$$\int z\,dy = \frac{1}{\sqrt{11.6}}\int y^{0.5}dy = \frac{1}{1.5\sqrt{11.6}}\,y^{1.5} = \boxed{0.1957\,y^{1.5}}$$

Problem 1.68

Solve for the function $P(V) = 1000/V$

$$\int P\,dV = \int 1000V^{-1}dV = \boxed{1000\ln V}$$

This function of pressure and volume will be found for a polytropic process.

Problem 1.69

$$h(T) = \int c\, dT = \int \left[11.515 - 172T^{-0.5} + 1530T^{-1} + \frac{0.05}{1000}(T - 4000) \right] dT$$

$$= 11.515\, T - \frac{172}{0.5} T^{0.5} + 1530 \ln T + \frac{0.05}{2(1000)} T^2 - \frac{0.05(4000)}{1000} T$$

$$\boxed{= 1.515\, T - 344T^{0.5} + 1530 \ln T + 2.5e^{-5} T^2 - 0.2T}$$

Chapter 2 Solutions

Chapter 2 Problem Subject Areas

2.1–2.48	State and calorific properties: definitions, units, and conversions
2.49–2.81	State and calorific properties: definitions, units, and conversions
2.82–2.91	Ideal gases: Process relationships
2.92–2.106	Real gases: tabulated properties, generalized compressibility, and van der Waals equation of state
2.107–2.160	Pure substances with liquid and vapor phases
2.161–2.162	Solids