## Thermodynamics

**1-1C** Classical thermodynamics is based on experimental observations whereas statistical thermodynamics is based on the average behavior of large groups of particles.

**1-2C** On a downhill road the potential energy of the bicyclist is being converted to kinetic energy, and thus the bicyclist picks up speed. There is no creation of energy, and thus no violation of the conservation of energy principle.

**1-3C** A car going uphill without the engine running would increase the energy of the car, and thus it would be a violation of the first law of thermodynamics. Therefore, this cannot happen. Using a level meter (a device with an air bubble between two marks of a horizontal water tube) it can shown that the road that looks uphill to the eye is actually downhill.

**1-4C** There is no truth to his claim. It violates the second law of thermodynamics.

## Mass, Force, and Units

**1-5C** Kg-mass is the mass unit in the SI system whereas kg-force is a force unit. 1-kg-force is the force required to accelerate a 1-kg mass by 9.807 $m/s^2$. In other words, the weight of 1-kg mass at sea level is 1 kg-force.

**1-6C** In this unit, the word *light* refers to the speed of light. The light-year unit is then the product of a velocity and time. Hence, this product forms a distance dimension and unit.

**1-7C** There is no acceleration, thus the net force is zero in both cases.

**1-8** The variation of gravitational acceleration above the sea level is given as a function of altitude. The height at which the weight of a body will decrease by 0.3% is to be determined.

***Analysis*** The weight of a body at the elevation z can be expressed as

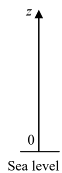
$$W = mg = m(9.807 - 3.32 \times 10^{-6} z)$$

In our case,

$$W = (1 - 0.3/100)W_s = 0.997W_s = 0.997mg_s = 0.997(m)(9.807)$$

Substituting,

$$0.997(9.807) = (9.807 - 3.32 \times 10^{-6} z) \longrightarrow z = \mathbf{8862\,m}$$



**1-9** The mass of an object is given. Its weight is to be determined.

***Analysis*** Applying Newton's second law, the weight is determined to be

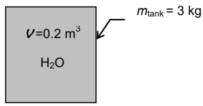
$$W = mg = (200\,\text{kg})(9.6\,\text{m/s}^2) = \mathbf{1920N}$$

**1-10** A plastic tank is filled with water. The weight of the combined system is to be determined.

***Assumptions*** The density of water is constant throughout.

***Properties*** The density of water is given to be $\rho$ = 1000 kg/m$^3$.

***Analysis*** The mass of the water in the tank and the total mass are




$$m_w = \rho V = (1000\text{ kg/m}^3)(0.2\text{ m}^3) = 200\text{ kg}$$

$$m_{total} = m_w + m_{tank} = 200 + 3 = 203\text{ kg}$$

Thus,

$$W = mg = (203\text{ kg})(9.81\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = \mathbf{1991\ N}$$

**1-11E** The constant-pressure specific heat of air given in a specified unit is to be expressed in various units.

***Analysis*** Using proper unit conversions, the constant-pressure specific heat is determined in various units to be

$$c_p = (1.005\,\text{kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1\,\text{kJ/kg}\cdot\text{K}}{1\,\text{kJ/kg}\cdot{}^\circ\text{C}}\right) = \mathbf{1.005 kJ/kg\cdot K}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1000\,\text{J}}{1\,\text{kJ}}\right)\left(\frac{1\,\text{kg}}{1000\,\text{g}}\right) = \mathbf{1.005 J/g\cdot{}^\circ C}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1\,\text{kcal}}{4.1868\,\text{kJ}}\right) = \mathbf{0.240 kcal/kg\cdot{}^\circ C}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1\,\text{Btu/lbm}\cdot{}^\circ\text{F}}{4.1868\,\text{kJ/kg}\cdot{}^\circ\text{C}}\right) = \mathbf{0.240 Btu/lbm\cdot{}^\circ F}$$

**1-12** A rock is thrown upward with a specified force. The acceleration of the rock is to be determined.

***Analysis*** The weight of the rock is

$$W = mg = (3\text{ kg})(9.79\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = 29.37\text{ N}$$

Stone

Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 200 - 29.37 = 170.6\text{ N}$$

From the Newton's second law, the acceleration of the rock becomes

$$a = \frac{F}{m} = \frac{170.6\text{ N}}{3\text{ kg}}\left(\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}\right) = \mathbf{56.9\ m/s^2}$$

**1-13** Problem 1-12 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.

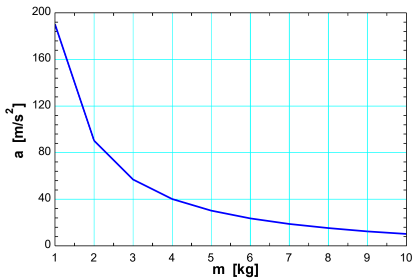
***Analysis*** The problem is solved using EES, and the solution is given below.

```
"The weight of the rock is"
W=m*g
m=3 [kg]
g=9.79 [m/s2]
"The force balance on the rock yields the net force acting on the rock as"
F_up=200 [N]
F_net = F_up - F_down
F_down=W
"The acceleration of the rock is determined from Newton's second law."
F_net=m*a

"To Run the program, press F2 or select Solve from the Calculate menu."

SOLUTION
a=56.88 [m/s^2]
F_down=29.37 [N]
F_net=170.6 [N]
F_up=200 [N]
g=9.79 [m/s2]
m=3 [kg]
W=29.37 [N]
```

| m [kg] | a [m/s$^2$] |
|---|---|
| 1 | 190.2 |
| 2 | 90.21 |
| 3 | 56.88 |
| 4 | 40.21 |
| 5 | 30.21 |
| 6 | 23.54 |
| 7 | 18.78 |
| 8 | 15.21 |
| 9 | 12.43 |
| 10 | 10.21 |



**1-14** A resistance heater is used to heat water to desired temperature. The amount of electric energy used in kWh and kJ are to be determined.

***Analysis*** The resistance heater consumes electric energy at a rate of 4 kW or 4 kJ/s. Then the total amount of electric energy used in 3 hours becomes

Total energy = (Energy per unit time)(Time interval)

= (4 kW)(3 h)

= **12 kWh**

Noting that 1 kWh = (1 kJ/s)(3600 s) = 3600 kJ,

Total energy = (12 kWh)(3600 kJ/kWh)

= **43,200 kJ**

***Discussion*** Note kW is a unit for power whereas kWh is a unit for energy.

**1-15E** An astronaut took his scales with him to space. It is to be determined how much he will weigh on the spring and beam scales in space.

***Analysis*** (*a*) A spring scale measures weight, which is the local gravitational force applied on a body:

$$W = mg = (150\ \text{lbm})(5.48\ \text{ft/s}^2)\left(\frac{1\ \text{lbf}}{32.2\ \text{lbm}\cdot\text{ft/s}^2}\right) = \mathbf{25.5\ lbf}$$

(*b*) A beam scale compares masses and thus is not affected by the variations in gravitational acceleration. The beam scale will read what it reads on earth,

$$W = \mathbf{150\ lbf}$$

**1-16** A gas tank is being filled with gasoline at a specified flow rate. Based on unit considerations alone, a relation is to be obtained for the filling time.

***Assumptions*** Gasoline is an incompressible substance and the flow rate is constant.

***Analysis*** The filling time depends on the volume of the tank and the discharge rate of gasoline. Also, we know that the unit of time is 'seconds'. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

$$t\ [\text{s}] \leftrightarrow V\ [\text{L}],\ \text{and}\ \dot{V}\ [\text{L/s}\}$$

It is obvious that the only way to end up with the unit "s" for time is to divide the tank volume by the discharge rate. Therefore, the desired relation is

$$\boxed{t = \frac{V}{\dot{V}}}$$

***Discussion*** Note that this approach may not work for cases that involve dimensionless (and thus unitless) quantities.

**1-17** A pool is to be filled with water using a hose. Based on unit considerations, a relation is to be obtained for the volume of the pool.

***Assumptions*** Water is an incompressible substance and the average flow velocity is constant.

***Analysis*** The pool volume depends on the filling time, the cross-sectional area which depends on hose diameter, and flow velocity. Also, we know that the unit of volume is $m^3$. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

$$V\ [\text{m}^3] \quad \text{is a function of} \quad t\ [\text{s}],\ D\ [\text{m}],\ \text{and}\ V\ [\text{m/s}\}$$

It is obvious that the only way to end up with the unit "$m^3$" for volume is to multiply the quantities $t$ and $V$ with the square of $D$. Therefore, the desired relation is

$$\boldsymbol{V = CD^2Vt}$$

where the constant of proportionality is obtained for a round hose, namely, $C = \pi/4$ so that $\boldsymbol{V = (\pi D^2/4)Vt}$.

***Discussion*** Note that the values of dimensionless constants of proportionality cannot be determined with this approach.

## Systems, Properties, State, and Processes

**1-18C** The radiator should be analyzed as an open system since mass is crossing the boundaries of the system.

**1-19C** The system is taken as the air contained in the piston-cylinder device. This system is a closed or fixed mass system since no mass enters or leaves it.

**1-20C** A can of soft drink should be analyzed as a closed system since no mass is crossing the boundaries of the system.

**1-21C** Intensive properties do not depend on the size (extent) of the system but extensive properties do.

**1-22C** If we were to divide the system into smaller portions, the weight of each portion would also be smaller. Hence, the weight is an *extensive property*.

**1-23C** Yes, because temperature and pressure are two independent properties and the air in an isolated room is a simple compressible system.

**1-24C** If we were to divide this system in half, both the volume and the number of moles contained in each half would be one-half that of the original system. The molar specific volume of the original system is

$$\bar{v} = \frac{V}{N}$$

and the molar specific volume of one of the smaller systems is

$$\bar{v} = \frac{V/2}{N/2} = \frac{V}{N}$$

which is the same as that of the original system. The molar specific volume is then an *intensive property*.

**1-25C** A process during which a system remains almost in equilibrium at all times is called a quasi-equilibrium process. Many engineering processes can be approximated as being quasi-equilibrium. The work output of a device is maximum and the work input to a device is minimum when quasi-equilibrium processes are used instead of nonquasi-equilibrium processes.

**1-26C** A process during which the temperature remains constant is called isothermal; a process during which the pressure remains constant is called isobaric; and a process during which the volume remains constant is called isochoric.

**1-27C** The pressure and temperature of the water are normally used to describe the state. Chemical composition, surface tension coefficient, and other properties may be required in some cases.

As the water cools, its pressure remains fixed. This cooling process is then an isobaric process.

**1-28C** When analyzing the acceleration of gases as they flow through a nozzle, the proper choice for the system is the volume within the nozzle, bounded by the entire inner surface of the nozzle and the inlet and outlet cross-sections. This is a control volume since mass crosses the boundary.

**1-29C** The **specific gravity,** or **relative density,** and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which $\rho_{H2O}$ = 1000 kg/m$^3$). That is, $SG = \rho / \rho_{H2O}$. When specific gravity is known, density is determined from $\rho = SG \times \rho_{H2O}$.

**1-30** The variation of density of atmospheric air with elevation is given in tabular form. A relation for the variation of density with elevation is to be obtained, the density at 7 km elevation is to be calculated, and the mass of the atmosphere using the correlation is to be estimated.

***Assumptions*** **1** Atmospheric air behaves as an ideal gas. **2** The earth is perfectly sphere with a radius of 6377 km, and the thickness of the atmosphere is 25 km.

***Properties*** The density data are given in tabular form as

| $r$, km | $z$, km | $\rho$, kg/m$^3$ |
|---|---|---|
| 6377 | 0 | 1.225 |
| 6378 | 1 | 1.112 |
| 6379 | 2 | 1.007 |
| 6380 | 3 | 0.9093 |
| 6381 | 4 | 0.8194 |
| 6382 | 5 | 0.7364 |
| 6383 | 6 | 0.6601 |
| 6385 | 8 | 0.5258 |
| 6387 | 10 | 0.4135 |
| 6392 | 15 | 0.1948 |
| 6397 | 20 | 0.08891 |
| 6402 | 25 | 0.04008 |

***Analysis*** Using EES, (1) Define a trivial function rho= a+z in equation window, (2) select new parametric table from Tables, and type the data in a two-column table, (3) select Plot and plot the data, and (4) select plot and click on "curve fit" to get curve fit window. Then specify 2$^{nd}$ order polynomial and enter/edit equation. The results are:

$\rho(z) = a + bz + cz^2 = 1.20252 - 0.101674z + 0.0022375z^2$ for the unit of kg/m$^3$,

(or, $\rho(z) = (1.20252 - 0.101674z + 0.0022375z^2)\times 10^9$ for the unit of kg/km$^3$)

where $z$ is the vertical distance from the earth surface at sea level. At $z$ = 7 km, the equation would give $\rho$ = 0.60 kg/m$^3$.

($b$) The mass of atmosphere can be evaluated by integration to be

$$m = \int_V \rho dV = \int_{z=0}^{h} (a+bz+cz^2)4\pi(r_0+z)^2 dz = 4\pi\int_{z=0}^{h} (a+bz+cz^2)(r_0^2+2r_0z+z^2)dz$$

$$= 4\pi\left[ar_0^2h + r_0(2a+br_0)h^2/2 + (a+2br_0+cr_0^2)h^3/3 + (b+2cr_0)h^4/4 + ch^5/5\right]$$

where $r_0$ = 6377 km is the radius of the earth, $h$ = 25 km is the thickness of the atmosphere, and $a$ = 1.20252, $b$ = -0.101674, and $c$ = 0.0022375 are the constants in the density function. Substituting and multiplying by the factor 10$^9$ for the density unity kg/km$^3$, the mass of the atmosphere is determined to be

$m$ = **5.092×10$^{18}$ kg**

***Discussion*** Performing the analysis with excel would yield exactly the same results.

EES Solution for final result:

```
a=1.2025166;        b=-0.10167
c=0.0022375;        r=6377;        h=25
m=4*pi*(a*r^2*h+r*(2*a+b*r)*h^2/2+(a+2*b*r+c*r^2)*h^3/3+(b+2*c*r)*h^4/4+c*h^5/5)*1E+9
```

## Temperature

**1-31C** They are Celsius (°C) and kelvin (K) in the SI, and fahrenheit (°F) and rankine (R) in the English system.

**1-32C** Probably, but not necessarily. The operation of these two thermometers is based on the thermal expansion of a fluid. If the thermal expansion coefficients of both fluids vary linearly with temperature, then both fluids will expand at the same rate with temperature, and both thermometers will always give identical readings. Otherwise, the two readings may deviate.

**1-33C** Two systems having different temperatures and energy contents are brought in contact. The direction of heat transfer is to be determined.

***Analysis*** Heat transfer occurs from warmer to cooler objects. Therefore, heat will be transferred from system B to system A until both systems reach the same temperature.

**1-34** A temperature is given in °C. It is to be expressed in K.

***Analysis*** The Kelvin scale is related to Celsius scale by

$$T(\text{K}) = T(°\text{C}) + 273$$

Thus,

$$T(\text{K}) = 37°\text{C} + 273 = \mathbf{310\ K}$$

**1-35E** The temperature of air given in °C unit is to be converted to °F and R unit.

***Analysis*** Using the conversion relations between the various temperature scales,

$$T(°\text{F}) = 1.8T(°\text{C}) + 32 = (1.8)(150) + 32 = \mathbf{302°F}$$
$$T(\text{R}) = T(°\text{F}) + 460 = 302 + 460 = \mathbf{762 R}$$

**1-36** A temperature change is given in °C. It is to be expressed in K.

***Analysis*** This problem deals with temperature changes, which are identical in Kelvin and Celsius scales. Thus,

$$\Delta T(\text{K}) = \Delta T(°\text{C}) = \mathbf{70\ K}$$

**1-37E** The flash point temperature of engine oil given in °F unit is to be converted to K and R units.

***Analysis*** Using the conversion relations between the various temperature scales,

$$T(\mathrm{R}) = T(°\mathrm{F}) + 460 = 363 + 460 = \mathbf{823R}$$

$$T(\mathrm{K}) = \frac{T(\mathrm{R})}{1.8} = \frac{823}{1.8} = \mathbf{457K}$$

**1-38E** The temperature of ambient air given in °C unit is to be converted to °F, K and R units.

***Analysis*** Using the conversion relations between the various temperature scales,

$$T = -40°\mathrm{C} = (-40)(1.8) + 32 = \mathbf{-40°F}$$

$$T = -40 + 273.15 = \mathbf{233.15K}$$

$$T = -40 + 459.67 = \mathbf{419.67R}$$

**1-39E** A temperature change is given in °F. It is to be expressed in °C, K, and R.

***Analysis*** This problem deals with temperature changes, which are identical in Rankine and Fahrenheit scales. Thus,

$$\Delta T(\mathrm{R}) = \Delta T(°\mathrm{F}) = 45\ \mathbf{R}$$

The temperature changes in Celsius and Kelvin scales are also identical, and are related to the changes in Fahrenheit and Rankine scales by

$$\Delta T(\mathrm{K}) = \Delta T(\mathrm{R})/1.8 = 45/1.8 = \mathbf{25\ K}$$

and $$\Delta T(°\mathrm{C}) = \Delta T(\mathrm{K}) = \mathbf{25°C}$$

## Pressure, Manometer, and Barometer

**1-40C** The atmospheric pressure, which is the external pressure exerted on the skin, decreases with increasing elevation. Therefore, the pressure is lower at higher elevations. As a result, the difference between the blood pressure in the veins and the air pressure outside increases. This pressure imbalance may cause some thin-walled veins such as the ones in the nose to burst, causing bleeding. The shortness of breath is caused by the lower air density at higher elevations, and thus lower amount of oxygen per unit volume.

**1-41C** The blood vessels are more restricted when the arm is parallel to the body than when the arm is perpendicular to the body. For a constant volume of blood to be discharged by the heart, the blood pressure must increase to overcome the increased resistance to flow.

**1-42C** No, the absolute pressure in a liquid of constant density does not double when the depth is doubled. It is the *gage pressure* that doubles when the depth is doubled.

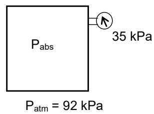
**1-43C** *Pascal's principle* states that *the pressure applied to a confined fluid increases the pressure throughout by the same amount*. This is a consequence of the pressure in a fluid remaining constant in the horizontal direction. An example of Pascal's principle is the operation of the hydraulic car jack.

**1-44C** The density of air at sea level is higher than the density of air on top of a high mountain. Therefore, the volume flow rates of the two fans running at identical speeds will be the same, but the mass flow rate of the fan at sea level will be higher.

**1-45** The pressure in a vacuum chamber is measured by a vacuum gage. The absolute pressure in the chamber is to be determined.

***Analysis*** The absolute pressure in the chamber is determined from

$$P_{abs} = P_{atm} - P_{vac} = 92 - 35 = \mathbf{57\ kPa}$$




**1-46** The pressure in a tank is given. The tank's pressure in various units are to be determined.

***Analysis*** Using appropriate conversion factors, we obtain

(*a*) $$P = (1200\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right) = \mathbf{1200 kN/m^2}$$

(*b*) $$P = (1200\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right)\left(\frac{1000\text{ kg}\cdot\text{m/s}^2}{1\text{ kN}}\right) = \mathbf{1{,}200{,}000 kg/m\cdot s^2}$$

(*c*) $$P = (1200\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right)\left(\frac{1000\text{ kg}\cdot\text{m/s}^2}{1\text{ kN}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right) = \mathbf{1{,}200{,}000000 kg/km\cdot s^2}$$