Solutions Manual

for

Introduction to Thermodynamics and Heat Transfer

Yunus A. Cengel

2nd Edition, 2008

Chapter 1

INTRODUCTION AND OVERVIEW

Thermodynamics, Heat Transfer, and Fluid Mechanics

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 There is no truth to his claim. It violates the second law of thermodynamics.

1-4C 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.

1-5C Thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another. Heat transfer, on the other hand, deals with the rate of heat transfer as well as the temperature distribution within the system at a specified time.

1-6C (a) The driving force for heat transfer is the temperature difference. (b) The driving force for electric current flow is the electric potential difference (voltage). (a) The driving force for fluid flow is the pressure difference.

1-7C Heat transfer is a non-equilibrium phenomena since in a system that is in equilibrium there can be no temperature differences and thus no heat flow.

1-8C No, there cannot be any heat transfer between two bodies that are at the same temperature (regardless of pressure) since the driving force for heat transfer is temperature difference.

1-9C The absolute minimum energy needed to move this car horizontally is zero since the acceleration is zero. Note that Force = mass × acceleration and Work = Force × distance.

Mass, Force, and Units

1-10C Pound-mass lbm is the mass unit in English system whereas pound-force lbf is the force unit. One pound-force is the force required to accelerate a mass of 32.174 lbm by 1 ft/s^2. In other words, the weight of a 1-lbm mass at sea level is 1 lbf.

1-11C 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.

1-12C There is no acceleration, thus the net force is zero in both cases.

1-13E The weight of a man on earth is given. His weight on the moon is to be determined.

Analysis Applying Newton's second law to the weight force gives

$$W = mg \longrightarrow m = \frac{W}{g} = \frac{180\ \text{lbf}}{32.10\ \text{ft/s}^2}\left(\frac{32.174\ \text{lbm}\cdot\text{ft/s}^2}{1\ \text{lbf}}\right) = 180.4\ \text{lbm}$$

Mass is invariant and the man will have the same mass on the moon. Then, his weight on the moon will be

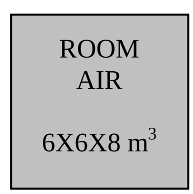
$$W = mg = (180.4\ \text{lbm})(5.47\ \text{ft/s}^2)\left(\frac{1\ \text{lbf}}{32.174\ \text{lbm}\cdot\text{ft/s}^2}\right) = \mathbf{30.7\ lbf}$$

1-14 The interior dimensions of a room are given. The mass and weight of the air in the room are to be determined.

Assumptions The density of air is constant throughout the room.

Properties The density of air is given to be ρ = 1.16 kg/m^3.

Analysis The mass of the air in the room is



$$m = \rho \boldsymbol{V} = (1.16\ \text{kg/m}^3)(6\times 6\times 8\ \text{m}^3) = \mathbf{334.1\ kg}$$

Thus,

$$W = mg = (334.1\ \text{kg})(9.81\ \text{m/s}^2)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right) = \mathbf{3277\ N}$$

1-15 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 1% is to be determined.

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

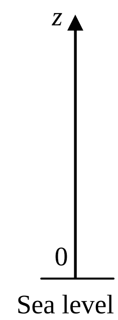
$$W = mg = m(9.807 - 3.32 \times 10^{-6} z)$$

In our case,

$$W = 0.99W_s = 0.99mg_s = 0.99(m)(9.807)$$

Substituting,

$$0.99(9.81) = (9.81 - 3.32 \times 10^{-6} z) \longrightarrow z = \mathbf{29{,}539\ m}$$



1-16E 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

$$W = mg = (10\ \text{lbm})(32.0\ \text{ft/s}^2)\left(\frac{1\ \text{lbf}}{32.174\ \text{lbm}\cdot\text{ft/s}^2}\right) = \mathbf{9.95\ lbf}$$

1-17 The acceleration of an aircraft is given in *g*'s. The net upward force acting on a man in the aircraft is to be determined.

Analysis From the Newton's second law, the force applied is

$$F = ma = m(6\ \text{g}) = (90\ \text{kg})(6 \times 9.81\ \text{m/s}^2)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right) = \mathbf{5297\ N}$$

1-18 CD EES 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

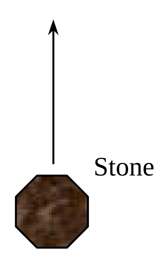
$$W = mg = (5\ \text{kg})(9.79\ \text{m/s}^2)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right) = 48.95\ \text{N}$$

Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 150 - 48.95 = 101.05\ \text{N}$$

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

$$a = \frac{F}{m} = \frac{101.05\ \text{N}}{5\ \text{kg}}\left(\frac{1\ \text{kg}\cdot\text{m/s}^2}{1\ \text{N}}\right) = \mathbf{20.2\ m/s^2}$$



1-19 EES Problem 1-18 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.

```
W=m*g "[N]"
m=5 [kg]
g=9.79 [m/s^2]

"The force balance on the rock yields the net force acting on the rock as"
F_net = F_up - F_down"[N]"
F_up=150 [N]
F_down=W"[N]"

"The acceleration of the rock is determined from Newton's second law."
F_net=a*m

"To Run the program, press F2 or click on the calculator icon from the Calculate menu"

SOLUTION
a=20.21 [m/s^2]
F_down=48.95 [N]
F_net=101.1 [N]
F_up=150 [N]
g=9.79 [m/s^2]
m=5 [kg]
W=48.95 [N]
```

1-20 Gravitational acceleration g and thus the weight of bodies decreases with increasing elevation. The percent reduction in the weight of an airplane cruising at 13,000 m is to be determined.

Properties The gravitational acceleration g is given to be 9.807 m/s^2 at sea level and 9.767 m/s^2 at an altitude of 13,000 m.

Analysis Weight is proportional to the gravitational acceleration g, and thus the percent reduction in weight is equivalent to the percent reduction in the gravitational acceleration, which is determined from

$$\%\text{Reduction in weight} = \%\text{Reduction in } g = \frac{\Delta g}{g}\times 100 = \frac{9.807 - 9.767}{9.807}\times 100 = \mathbf{0.41\%}$$

Therefore, the airplane and the people in it will weight 0.41% less at 13,000 m altitude.

Discussion Note that the weight loss at cruising altitudes is negligible.

Modeling and Solving Engineering problems

1-21C The *rating* problems deal with the determination of the *heat transfer rate* for an existing system at a specified temperature difference. The *sizing* problems deal with the determination of the *size* of a system in order to transfer heat at a *specified rate* for a *specified temperature difference*.

1-22C The experimental approach (testing and taking measurements) has the advantage of dealing with the actual physical system, and getting a physical value within the limits of experimental error. However, this approach is expensive, time consuming, and often impractical. The analytical approach (analysis or calculations) has the advantage that it is fast and inexpensive, but the results obtained are subject to the accuracy of the assumptions and idealizations made in the analysis.

1-23C Modeling makes it possible to predict the course of an event before it actually occurs, or to study various aspects of an event mathematically without actually running expensive and time-consuming experiments. When preparing a mathematical model, all the variables that affect the phenomena are identified, reasonable assumptions and approximations are made, and the interdependence of these variables are studied. The relevant physical laws and principles are invoked, and the problem is formulated mathematically. Finally, the problem is solved using an appropriate approach, and the results are interpreted.

1-24C The right choice between a crude and complex model is usually the *simplest* model which yields *adequate* results. Preparing very accurate but complex models is not necessarily a better choice since such models are not much use to an analyst if they are very difficult and time consuming to solve. At the minimum, the model should reflect the essential features of the physical problem it represents.

Solving Engineering Problems and EES

1-25C Despite the convenience and capability the engineering software packages offer, they are still just tools, and they will not replace the traditional engineering courses. They will simply cause a shift in emphasis in the course material from mathematics to physics. They are of great value in engineering practice, however, as engineers today rely on software packages for solving large and complex problems in a short time, and perform optimization studies efficiently.

1-26 EES Determine a positive real root of the following equation using EES:

$$2x^3 - 10x^{0.5} - 3x = -3$$

Solution by EES Software (Copy the following line and paste on a blank EES screen to verify solution):

```
2*x^3-10*x^0.5-3*x = -3
```

Answer: x = 2.063 (using an initial guess of x=2)

1-27 EES Solve the following system of 2 equations with 2 unknowns using EES:

$x^3 - y^2 = 7.75$

$3xy + y = 3.5$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
x^3-y^2=7.75
3*x*y+y=3.5
```

Answer x=2 y=0.5

1-28 EES Solve the following system of 3 equations with 3 unknowns using EES:

$2x - y + z = 5$

$3x^2 + 2y = z + 2$

$xy + 2z = 8$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
2*x-y+z=5
3*x^2+2*y=z+2
x*y+2*z=8
```

Answer x=1.141, y=0.8159, z=3.535

1-29 EES Solve the following system of 3 equations with 3 unknowns using EES:

$x^2y - z = 1$

$x - 3y^{0.5} + xz = -2$

$x + y - z = 2$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
x^2*y-z=1
x-3*y^0.5+x*z=-2
x+y-z=2
```

Answer x=1, y=1, z=0

1-30E EES Specific heat of water is to be expressed at various units using unit conversion capability of EES.

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

EQUATION WINDOW

```
"GIVEN"
C_p=4.18 [kJ/kg-C]

"ANALYSIS"
C_p_1=C_p*Convert(kJ/kg-C, kJ/kg-K)
C_p_2=C_p*Convert(kJ/kg-C, Btu/lbm-F)
C_p_3=C_p*Convert(kJ/kg-C, Btu/lbm-R)
C_p_4=C_p*Convert(kJ/kg-C, kCal/kg-C)
```

FORMATTED EQUATIONS WINDOW

GIVEN

$$C_p = 4.18 \quad [\mathrm{kJ/kg\text{-}C}]$$

ANALYSIS

$$C_{p,1} = C_p \cdot \left| 1 \cdot \frac{\mathrm{kJ/kg\text{–}K}}{\mathrm{kJ/kg\text{–}C}} \right|$$

$$C_{p,2} = C_p \cdot \left| 0.238846 \cdot \frac{\mathrm{Btu/lbm\text{–}F}}{\mathrm{kJ/kg\text{–}C}} \right|$$

$$C_{p,3} = C_p \cdot \left| 0.238846 \cdot \frac{\mathrm{Btu/lbm\text{–}R}}{\mathrm{kJ/kg\text{–}C}} \right|$$

$$C_{p,4} = C_p \cdot \left| 0.238846 \cdot \frac{\mathrm{kCal/kg\text{–}C}}{\mathrm{kJ/kg\text{–}C}} \right|$$

SOLUTION WINDOW

```
C_p=4.18 [kJ/kg-C]
C_p_1=4.18 [kJ/kg-K]
C_p_2=0.9984 [Btu/lbm-F]
C_p_3=0.9984 [Btu/lbm-R]
C_p_4=0.9984 [kCal/kg-C]
```

Review Problems

1-31 The weight of a lunar exploration module on the moon is to be determined.

Analysis Applying Newton's second law, the weight of the module on the moon can be determined from

$$W_{\text{moon}} = mg_{\text{moon}} = \frac{W_{\text{earth}}}{g_{\text{earth}}} g_{\text{moon}} = \frac{4000\text{ N}}{9.8\text{ m/s}^2}(1.64\text{ m/s}^2) = \mathbf{669\ N}$$

1-32 The gravitational acceleration changes with altitude. Accounting for this variation, the weights of a body at different locations are to be determined.

Analysis The weight of an 80-kg man at various locations is obtained by substituting the altitude z (values in m) into the relation

$$W = mg = (80\text{kg})(9.807 - 3.32 \times 10^{-6} z\text{ m/s}^2)\left(\frac{1\text{N}}{1\text{kg} \cdot \text{m/s}^2}\right)$$

Sea level: (z = 0 m): W = 80×(9.807-3.32x10^{-6}×0) = 80×9.807 = **784.6 N**

Denver: (z = 1610 m): W = 80×(9.807-3.32x10^{-6}×1610) = 80×9.802 = **784.2 N**

Mt. Ev.: (z = 8848 m): W = 80×(9.807-3.32x10^{-6}×8848) = 80×9.778 = **782.2 N**

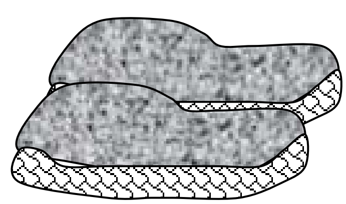
1-33E A man is considering buying a 12-oz steak for \$3.15, or a 320-g steak for \$2.80. The steak that is a better buy is to be determined.

Assumptions The steaks are of identical quality.

Analysis To make a comparison possible, we need to express the cost of each steak on a common basis. Let us choose 1 kg as the basis for comparison. Using proper conversion factors, the unit cost of each steak is determined to be

12 ounce steak:

$$\text{Unit Cost} = \left(\frac{\$3.15}{12\text{ oz}}\right)\left(\frac{16\text{ oz}}{1\text{ lbm}}\right)\left(\frac{1\text{ lbm}}{0.45359\text{ kg}}\right) = \mathbf{\$9.26/kg}$$



320 gram steak:

$$\text{Unit Cost} = \left(\frac{\$2.80}{320\text{ g}}\right)\left(\frac{1000\text{ g}}{1\text{ kg}}\right) = \mathbf{\$8.75/kg}$$

Therefore, the steak at the international market is a better buy.

1-34E The thrust developed by the jet engine of a Boeing 777 is given to be 85,000 pounds. This thrust is to be expressed in N and kgf.

Analysis Noting that 1 lbf = 4.448 N and 1 kgf = 9.81 N, the thrust developed can be expressed in two other units as

Thrust in N: $$\text{Thrust} = (85{,}000\ \text{lbf})\left(\frac{4.448\ \text{N}}{1\ \text{lbf}}\right) = \mathbf{3.78 \times 10^5\ N}$$

Thrust in kgf: $$\text{Thrust} = (37.8 \times 10^5\ \text{N})\left(\frac{1\ \text{kgf}}{9.81\ \text{N}}\right) = \mathbf{3.85 \times 10^4\ kgf}$$

1-35 Design and Essay Problems