1.6 If Superman has a mass of 100 kg on his birth planet Krypton, where the acceleration of gravity is 25 m/s², determine (a) his weight on Krypton, in N, and (b) his mass, in kg, and weight, in N, on Earth where \( g = 9.81 \text{ m/s}^2 \).

1.7 A person whose mass is 150 lb weighs 144.4 lbf. Determine (a) the local acceleration of gravity, in ft/s², and (b) the person’s mass, in lb and weight, in lbf, if \( g = 32.174 \text{ ft/s}^2 \).

1.8 A gas occupying a volume of 25 ft³ weighs 3.5 lbf on the moon, where the acceleration of gravity is 5.47 ft/s². Determine its weight, in lbf, and density, in lb/ft³, on Mars, where \( g = 12.86 \text{ ft/s}^2 \).

1.9 In severe head-on automobile accidents, a deceleration of 60 g’s or more (1 g = 32.2 ft/s²) often results in a fatality. What force, in lbf, acts on a child whose mass is 50 lb, when subjected to a deceleration of 60 g’s?

1.10 Atomic and molecular weights of some common substances are listed in Appendix Tables A-1 and A-1E. Using data from the appropriate table, determine

(a) the mass, in kg, of 10 kmol of each of the following: \( \text{H}_2 \text{O} \), \( \text{Cu} \), \( \text{SO}_2 \),

(b) the number of lbf mol in 20 lb of each of the following: \( \text{Ar} \), \( \text{H}_2 \), \( \text{N}_2 \), \( \text{C} \).

1.11 When an object of mass 5 kg is suspended from a spring, the spring is observed to stretch by 8 cm. The deflection of the spring is related linearly to the weight of the suspended mass. What is the proportionality constant, in newtons per cm, if \( g = 9.81 \text{ m/s}^2 \)?

1.12 A spring compresses in length by 0.12 in. for every 1 lbf of applied force. Determine the deflection, in inches, of the spring caused by the weight of an object whose mass is 15 lb. The local acceleration of gravity is \( g = 31.4 \text{ ft/s}^2 \).

1.13 A simple instrument for measuring the acceleration of gravity employs a linear spring from which a mass is suspended. At a location on Earth where the acceleration of gravity is 32.174 ft/s², the spring extends 0.291 in. If the spring extends 0.116 in. when the instrument is on Mars, what is the Martian acceleration of gravity? How much would the spring extend on the moon, where \( g = 5.47 \text{ ft/s}^2 \)?

1.14 Estimate the magnitude of the force, in lbf, exerted by a seat belt on a 200-lb driver during a frontal collision that decelerates a car from 10 mi/h to rest in 0.1 s. Express the car’s deceleration in multiples of the standard acceleration of gravity, or g’s.

1.15 An object whose mass is 2 kg is subjected to an applied upward force. The only other force acting on the object is the force of gravity. The net acceleration of the object is upward with a magnitude of 5 m/s². The acceleration of gravity is 9.81 m/s². Determine the magnitude of the applied upward force, in N.

1.16 An object whose mass is 35 lb is subjected to an applied upward force of 15 lbf. The only other force acting on the object is the force of gravity. Determine the net acceleration of the object, in ft/s², assuming the acceleration of gravity is constant, \( g = 32.2 \text{ ft/s}^2 \). Is the net acceleration upward or downward?

1.17 An astronaut weighs 700 N on Earth where \( g = 9.81 \text{ m/s}^2 \). What is the astronaut’s weight, in N, on an orbiting space
station where the acceleration of gravity is 6 m/s²? Express each weight in lbf.

1.18 If the variation of the acceleration of gravity, in m/s², with elevation z, in m, above sea level is \( g = 9.81 - (3.3 \times 10^{-6})z \), determine the percent change in weight of an airliner landing from a cruising altitude of 10 km on a runway at sea level.

1.19 The storage tank of a water tower is nearly spherical in shape with a radius of 30 ft. If the density of the water is 62.4 lb/ft³, what is the mass of water stored in the tower, in lb, when the tank is full? What is the weight, in lbf, of the water if the local acceleration of gravity is 32.1 ft/s²?

1.20 As shown in Fig. P1.20, a cylinder of compacted scrap metal measuring 2 m in length and 0.5 m in diameter is suspended from a spring scale at a location where the acceleration of gravity is 9.78 m/s². If the scrap metal density, in kg/m³, varies with position z, in m, according to \( \rho = 7800 - 360(z/L)^2 \), determine the reading of the scale, in N.

![Fig. P1.20](image)

Using Specific Volume and Pressure

1.21 A closed system consists of 0.5 kmol of ammonia occupying a volume of 6 m³. Determine (a) the weight of the system, in N, and (b) the specific volume, in m³/kmol and m³/kg. Let \( g = 9.81 \) m/s².

1.22 A spherical balloon holding 35 lb of air has a diameter of 10 ft. For the air, determine (a) the specific volume, in ft³/lb and ft³/lbmol, and (b) the weight, in lbf. Let \( g = 31.0 \) ft/s².

1.23 A closed vessel having a volume of 1 liter holds 2.5 \times 10^{22} molecules of ammonia vapor. For the ammonia, determine (a) the amount present, in kg and kmol, and (b) the specific volume, in m³/kg and m³/kmol.

1.24 The specific volume of water vapor at 0.3 MPa, 160°C is 0.651 m³/kg. If the water vapor occupies a volume of 2 m³, determine (a) the amount present, in kg and kmol, and (b) the number of molecules.

1.25 Fifteen kg of carbon dioxide (CO₂) gas is fed to a cylinder having a volume of 20 m³ and initially containing 15 kg of CO₂ at a pressure of 10 bar. Later a pinhole develops and the gas slowly leaks from the cylinder. (a) Determine the specific volume, in m³/kg, of the CO₂ in the cylinder initially. Repeat for the CO₂ in the cylinder after the 15 kg has been added.

(b) Plot the amount of CO₂ that has leaked from the cylinder, in kg, versus the specific volume of the CO₂ remaining in the cylinder. Consider \( v \) ranging up to 1.0 m³/kg.

1.26 Go to [http://www.weather.gov](http://www.weather.gov) for weather data at three locations of your choice. At each location express the local atmospheric pressure in bar and atmospheres.

1.27 A closed system consisting of 5 kg of a gas undergoes a process during which the relationship between pressure and specific volume is \( pV^n = constant \). The process begins with \( p_1 = 1 \) bar, \( v_1 = 0.2 \) m³/kg and ends with \( p_2 = 0.25 \) bar. Determine the final volume, in m³, and plot the process on a graph of pressure versus specific volume.

1.28 A closed system consisting of 2 lb of a gas undergoes a process during which the relation between pressure and volume is \( pV^n = constant \). The process begins with \( p_1 = 20 \) lbf/in.², \( V_1 = 10 \) ft³ and ends with \( p_2 = 100 \) lbf/in.², \( V_2 = 2.9 \) ft³. Determine (a) the value of \( n \) and (b) the specific volume at states 1 and 2, each in ft³/lbf. (c) Sketch the process on pressure-volume coordinates.

1.29 A system consists of nitrogen (N₂) in a piston–cylinder assembly, initially at \( p_1 = 20 \) lbf/in.², and occupying a volume of 2.5 ft³. The nitrogen is compressed to \( p_2 = 100 \) lbf/in.², and a final volume of 1.5 ft³. During the process, the relation between pressure and volume is linear. Determine the pressure, in lbf/in.², at an intermediate state where the volume is 2.1 ft³, and sketch the process on a graph of pressure versus volume.

1.30 A gas initially at \( p_1 = 1 \) bar and occupying a volume of 1 liter is compressed within a piston–cylinder assembly to a final pressure \( p_2 = 4 \) bar.

(a) If the relationship between pressure and volume during the compression is \( pV = constant \), determine the volume, in liters, at a pressure of 3 bar. Also plot the overall process on a graph of pressure versus volume.

(b) Repeat for a linear pressure–volume relationship between the same end states.

1.31 A gas contained within a piston–cylinder assembly undergoes three processes in series:

**Process 1-2:** Compression with \( pV = constant \) from \( p_1 = 1 \) bar, \( V_1 = 1.0 \) m³ to \( V_2 = 0.2 \) m³

**Process 2-3:** Constant-pressure expansion to \( V_3 = 1.0 \) m³

**Process 3-1:** Constant volume

Sketch the processes in series on a \( p-V \) diagram labeled with pressure and volume values at each numbered state.

1.32 As shown in Fig. 1.7, a manometer is attached to a tank of gas in which the pressure is 104.0 kPa. The manometer liquid is mercury, with a density of 13.59 g/cm³. If \( g = 9.81 \) m/s² and the atmospheric pressure is 101.33 kPa, calculate

(a) the difference in mercury levels in the manometer, in cm.

(b) the gage pressure of the gas, in kPa.

1.33 A vacuum gage at the intake duct to a fan gives a reading of 4.2 in. of manometer fluid. The surrounding atmospheric pressure is 14.5 lbf/in.². Determine the absolute pressure inside
1.34 The absolute pressure inside a tank is 0.4 bar, and the surrounding atmospheric pressure is 98 kPa. What reading would a Bourdon gage mounted in the tank wall, give in kPa? Is this a gage or vacuum reading?

1.35 The barometer shown in Fig. P1.35 contains mercury ($\rho = 13.59$ g/cm$^3$). If the local atmospheric pressure is 100 kPa and $g = 9.81$ m/s$^2$, determine the height of the mercury column, $L$, in mmHg and inHg.

![Fig. P1.35](image)

1.36 Water flows through a Venturi meter, as shown in Fig. P1.36. The pressure of the water in the pipe supports columns of water that differ in height by 10 in. Determine the difference in pressure between points a and b, in lbff/in.$^2$. Does the pressure increase or decrease in the direction of flow? The atmospheric pressure is 14.7 lbff/in.$^2$, the specific volume of water is 0.01604 ft$^3$/lb, and the acceleration of gravity is $g = 32.0$ ft/s$^2$.

![Fig. P1.36](image)

1.37 Figure P1.37 shows a tank within a tank, each containing air. The absolute pressure in tank A is 267.7 kPa. Pressure gage A is located inside tank B and reads 140 kPa. The U-tube manometer connected to tank B contains mercury. Using data on the diagram, determine the absolute pressure inside tank B, in kPa, and the column length $L$, in cm. The atmospheric pressure surrounding tank B is 101 kPa. The acceleration of gravity is $g = 9.81$ m/s$^2$.

![Fig. P1.37](image)

1.38 As shown in Fig. P1.38, an underwater exploration vehicle submerges to a depth of 1000 ft. If the atmospheric pressure at the surface is 1 atm, the water density is 62.4 lbff/ft$^3$, and $g = 32.2$ ft/s$^2$, determine the pressure on the vehicle, in atm.

![Fig. P1.38](image)

1.39 A vacuum gage indicates that the pressure of carbon dioxide in a closed tank is −10 kPa. A mercury barometer gives the local atmospheric pressure as 750 mmHg. Determine the absolute pressure of the carbon dioxide, in kPa. The density of mercury is 13.59 g/cm$^3$ and $g = 9.81$ m/s$^2$.

1.40 Refrigerant 22 vapor enters the compressor of a refrigeration system at an absolute pressure of 20 lbff/in.$^2$. A pressure gage at the compressor exit indicates a pressure of 280 lbff/in.$^2$ (gage). The atmospheric pressure is 14.6 lbff/in.$^2$. Determine the change in absolute pressure from inlet to exit, in lbff/in.$^2$, and the ratio of exit to inlet pressure.

1.41 As shown in Fig. P1.41, air is contained in a vertical piston-cylinder assembly fitted with an electrical resistor. The atmosphere exerts a pressure of 14.7 lbff/in.$^2$ on the top of the
piston, which has a mass of 100 lb and face area of 1 ft². As electric current passes through the resistor, the volume of the air increases while the piston moves smoothly in the cylinder. The local acceleration of gravity is \( g = 32.0 \text{ ft/s}^2 \). Determine the pressure of the air in the piston-cylinder assembly, in lb/ft² and psig.

1.42 Warm air is contained in a piston-cylinder assembly oriented horizontally as shown in Fig. P1.42. The air cools slowly from an initial volume of 0.003 m³ to a final volume of 0.002 m³. During the process, the spring exerts a force that varies linearly from an initial value of 900 N to a final value of zero. The atmospheric pressure is 100 kPa, and the area of the piston face is 0.018 m². Friction between the piston and the cylinder wall can be neglected. For the air in the piston-cylinder assembly, determine the initial and final pressures, each in kPa and atm.

1.44 Determine the total force, in kN, on the bottom of a 100 × 50 m swimming pool. The depth of the pool varies linearly from 1 m to 4 m. Also, determine the pressure on the floor at the center of the pool, in kPa. The atmospheric pressure is 0.98 bar, the density of the water is 988.2 kg/m³, and the local acceleration of gravity is 9.8 m/s².

1.45 The pressure from water mains located at street level may be insufficient for delivering water to the upper floors of tall buildings. In such a case, water may be pumped up to a tank that feeds water to the building by gravity. For an open storage tank atop a 300-ft-tall building, determine the pressure, in lb/in², at the bottom of the tank when filled to a depth of 20 ft. The density of water is 62.2 lb/ft³, \( g = 32.0 \text{ ft/s}^2 \), and the local atmospheric pressure is 14.7 lb/in².

1.46 As shown in Figure P1.46, an inclined manometer is used to measure the pressure of the gas within the reservoir. (a) Using data on the figure, determine the gas pressure, in lb/in². (b) Express the pressure as a gage or a vacuum pressure, as appropriate, in lb/in². (c) What advantage does an inclined manometer have over the U-tube manometer shown in Figure 1.7?

1.47 The variation of pressure within the biosphere affects not only living things but also systems such as aircraft and undersea exploration vehicles.

(a) Plot the variation of atmospheric pressure, in atm, versus elevation \( z \) above sea level, in km, ranging from 0 to 10 km. Assume that the specific volume of the atmosphere, in m³/kg, varies with the local pressure \( p \), in kPa, according to \( v = 72.435/p \).

(b) Plot the variation of pressure, in atm, versus depth \( z \) below sea level, in km, ranging from 0 to 2 km. Assume
that the specific volume of seawater is constant, 

\[ v = 0.956 \times 10^{-3} \text{ m}^3/\text{kg}. \]

In each case, \( g = 9.81 \text{ m/s}^2 \) and the pressure at sea level is 1 atm.

**1.48** One thousand kg of natural gas at 100 bar and 255 K is stored in a tank. If the pressure, \( p \), specific volume, \( \nu \), and temperature, \( T \), of the gas are related by the following expression

\[ p = \left(\frac{5.18 \times 10^{-7}}{T}\right)\left(\frac{1}{\nu - 0.002668}\right) - \left(\frac{8.91 \times 10^{-3}}{\nu^3}\right) \]

where \( \nu \) is in m\(^3\)/kg, \( T \) is in K, and \( p \) is in bar, determine the volume of the tank, in m\(^3\). Also, plot pressure versus specific volume for the isotherms \( T = 250, 500, \) and 1000 K.

**1.49** An 82.3-ft\(^3\) tank contains water vapor at 1500 lbf/in.\(^2\) and 1140°F. If the pressure, \( p \), specific volume, \( \nu \), and temperature, \( T \), of water vapor are related by the expression

\[ p = \left(\frac{0.5954}{\nu - 0.2708}\right) - \left(\frac{63.36}{\nu^2}\right) \]

where \( \nu \) is in ft\(^3\)/lb, \( T \) is in °R, and \( p \) is in lbf/in.\(^2\), determine the mass of water in the tank. Also, plot pressure versus specific volume for the isotherms \( T = 1200, 1400, \) and 1600°R.

**Exploring Temperature**

**1.50** Convert the following temperatures from °C to °F:
- (a) 21°C, (b) -40°C, (c) 500°C, (d) 0°C, (e) 100°C, (f) -273.15°C. Convert each temperature to °R.

**1.51** Convert the following temperatures from °F to °C:
- (a) 68°F, (b) -40°F, (c) 500°F, (d) 0°F, (e) 212°F, (f) -459.67°F. Convert each temperature to °K.

**1.52** Natural gas is burned with air to produce gaseous products at 1985°C. Express this temperature in K, °R and °F.

**1.53** The temperature of a child ill with a fever is measured as 40°C. The child's normal temperature is 37°C. Express both temperatures in °F.

**1.54** Does the Rankine degree represent a larger or smaller temperature unit than the Kelvin degree? Explain.

**1.55** As shown in Fig. P1.55, a small-diameter water pipe passes through the 6-in.-thick exterior wall of a dwelling. Assuming that temperature varies linearly with position \( x \) through the wall from 68°F to 20°F, would the water in the pipe freeze? Explain.

**Fig. P1.55**

**1.56** What is (a) the lowest naturally occurring temperature recorded on Earth, (b) the lowest temperature recorded in a laboratory on Earth, (c) the lowest temperature recorded in the Earth's solar system, and (d) the temperature of deep space, each in K?

**1.57** What is the maximum increase and maximum decrease in body temperature, each in °C, from a normal body temperature of 37°C that humans can experience before serious medical complications result?

**1.58** For liquid-in-glass thermometers, the thermometric property is the change in length of the thermometer liquid with temperature. However, other effects are present that can affect the temperature reading of such thermometers. What are some of these?