9 Solids, Liquids, and Gases

9-1 Density

Vocabulary **Density:** A measure of how much mass occupies a given space.

$$\textbf{density} = \frac{\textbf{mass}}{\textbf{volume}} \quad \text{or} \quad D = \frac{m}{V}$$

The SI unit for density is the **kilogram per cubic meter (kg/m^3)**.

Density is a characteristic property of a material. The density of an object does not change if the object is broken into smaller pieces. Although each piece now has less mass than the original object, it has less volume as well. Therefore, the density remains the same.

Think of density as describing how "compact" an object is. Remember, the density of a material can change with temperature because atoms and molecules move faster when they are heated, and thus usually occupy more space.

Solved Examples

Example 1: While doing dishes, Zvi drops his 3.00×10^{-3}-kg platinum wedding band into the dishwater, displacing a volume of 1.40×10^{-7} m^3 of water. What is the density of the plantinum band?

Given: $m = 3.00 \times 10^{-3}$ kg
$V = 1.40 \times 10^{-7}$ m^3

Unknown: $D = ?$
Original equation: $D = \frac{m}{V}$

Solve: $D = \frac{m}{V} = \frac{3.00 \times 10^{-3}\ \text{kg}}{1.40 \times 10^{-7}\ \text{m}^3} = \mathbf{2.14 \times 10^4\ kg/m^3}$

Example 2: At a temperature of 4 °C, 5000. kg of water will fill a volume of 5.000 m^3. What is the density of water at 4 °C?

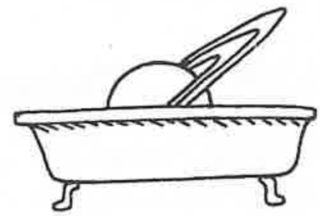
Given: $m = 5000.$ kg
$V = 5.000$ m^3

Unknown: $D = ?$
Original equation: $D = \frac{m}{V}$

Solve: $D = \frac{m}{V} = \frac{5000.\ \text{kg}}{5.000\ \text{m}^3} = \mathbf{1000.\ kg/m^3}$

Practice Exercises

Exercise 1: The planet Saturn has a mass of 5.69×10^{26} kg and a volume of 8.01×10^{23} m^3. a) What is the density of Saturn? b) Would Saturn sink or float if you could place it in a gigantic bathtub filled with water?



Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 2: You are handed a 5.00×10^{-3}-kg coin and told that it is gold. You discover that the coin has a volume of 5.90×10^{-7} m^3. You know that the density of gold is 19 300 kg/m^3. Have you really been handed a gold coin, or simply a good imitation?

Answer: ____________________

Exercise 3: Diamond has a density of 3520 kg/m^3. During a physics lab, a diamond drops out of Virginia's necklace and falls into her graduated cylinder filled with 5.00×10^{-5} m^3 of water. This causes the water level to rise to the 5.05×10^{-5}–m^3 mark. What is the mass of Virginia's diamond?

Answer: ____________________

Exercise 4: You are given three different liquids—water, oil and glycerin—and asked to predict which will occupy the top, middle, and bottom layers when all three are poured into the same beaker. You take down the following data:

	mass (in kg)	volume (in m^3)
water	0.1000	1.00×10^{-4}
oil	0.0500	5.39×10^{-5}
glycerin	0.0400	3.17×10^{-5}

By finding the densities, determine how these liquids will layer themselves in the beaker from top to bottom.

Answer: ____________________

9-2 Solids

Compression and Stretching

Vocabulary **Elasticity:** A property of a body that causes it to deform when a force is exerted and return to its original shape when the deforming force is removed, within certain limits.

Vocabulary **Stress:** The force exerted on an area divided by the area.

$$\textbf{stress} = \frac{\textbf{force}}{\textbf{area}} = \frac{F}{A}$$

The SI unit of stress is the **newton per square meter (N/m^2)**.

Vocabulary **Strain:** The ratio of change in dimension to original dimension.

Most often strain is used in describing the change in length of an object when a force is exerted.

$$\textbf{strain} = \frac{\textbf{change in length}}{\textbf{original length}} = \frac{\Delta L}{L}$$

Because strain is a ratio of lengths, it has no units.

Stress and strain are proportional to each other, and their ratio is equal to the elasticity of the material. The elasticity of a material is called the stretch modulus or **Young's modulus, Y**.

$$\textbf{Young's modulus} = \frac{\textbf{stress}}{\textbf{strain}} \quad \text{or} \quad Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$$

The SI unit for Young's modulus is the **newton per square meter (N/m²)**.

Shearing

Shearing is another way of applying stress to an object to cause a distortion. However, this type of distortion is not one of dimension, but one of shape. For example, the book in Figure A will look like the one in Figure B when it is sheared.

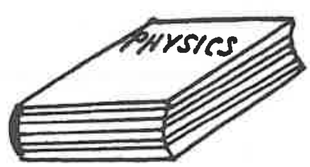


Figure A

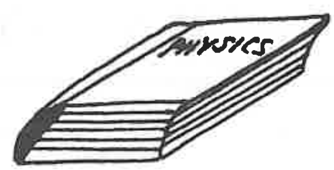


Figure B

In this case, the shearing stress is the force exerted on the area of one of the pages and the strain is the ratio of the horizontal distance the book moves, ΔL, to the original height of the book, L. The ratio of stress to strain is equal to the elastic modulus or the **shearing modulus, S**.

$$\textbf{shearing modulus} = \frac{\textbf{shearing stress}}{\textbf{shearing strain}} \quad \text{or} \quad S = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$$

Solved Examples

Example 3: Jason, the piano tuner, is tuning a 0.50-m-long steel piano wire of cross-sectional area 0.18 cm² by stretching it with a force of 1200 N. By how much does this lengthen the wire? ($Y_{steel} = 2.0 \times 10^{11}\ \text{N/m}^2$)

Solution: First, convert cm² to m². $0.18\ \text{cm}^2 = 1.8 \times 10^{-5}\ \text{m}^2$

Given: $L = 0.50\ \text{m}$
$F = 1200\ \text{N}$
$A = 1.8 \times 10^{-5}\ \text{m}^2$
$Y = 2.0 \times 10^{11}\ \text{N/m}^2$

Unknown: $\Delta L = ?$
Original equation: $Y = \dfrac{FL}{A\Delta L}$

Solve: $\Delta L = \frac{FL}{YA} = \frac{(1200\ \text{N})(0.50\ \text{m})}{(2.0 \times 10^{11}\ \text{N/m}^2)(1.8 \times 10^{-5}\ \text{m}^2)} = \mathbf{1.7 \times 10^{-4}\ m}$

Example 4: While writing his history research paper, Brent reaches across the library table for his dictionary and pulls it toward himself by the edge of the top cover with a force of 16 N, displacing the cover by 0.02 m. The top of the 0.05-m-thick dictionary measures 0.05 m^2. What is the shear modulus of the dictionary?

Given: $F = 16\ \text{N}$
$A = 0.05\ \text{m}^2$
$L = 0.05\ \text{m}$
$\Delta L = 0.02\ \text{m}$

Unknown: $S = ?$
Original equation: $S = \frac{FL}{A\Delta L}$

Solve: $S = \frac{FL}{A\Delta L} = \frac{(16\ \text{N})(0.05\ \text{m})}{(0.05\ \text{m}^2)(0.02\ \text{m})} = \mathbf{800\ N/m^2}$

Practice Exercises

Exercise 5: Two leopards are fighting over a piece of meat they caught while hunting. The leopards pull on the meat muscle with a force of 100. N, stretching the 0.10-m-long tendon by 0.0080 m. If the cross-sectional area of the tendon is $1.0 \times 10^{-5}\ \text{m}^2$, what is its stretch modulus?

Answer: ______________________

Exercise 6: Before heading out on her big date, Ling stands in front of the bathroom mirror brushing her 0.25-m-long hair with a force of 2.0 N. If the cross-sectional area of a piece of hair is $1.0 \times 10^{-7}\ \text{m}^2$, by how much does the hair stretch when it is brushed? ($Y_{\text{hair}} = 2.0 \times 10^9$ N)

Answer: ______________________

Exercise 7: When a piece of wood is distorted by a karate chop, the top of the board is compressed while the bottom is stretched as shown. Therefore, you must first consider the change in length of the bottom of the board where the break begins. Chantal is a black belt in karate and she breaks a 30.0-cm piece of wood with a force of 70.0 N, changing it in length by 4.0×10^{-4} cm. What is the cross-sectional area of the piece of wood? ($Y_{wood} = 1.0 \times 10^9$ N/m^2)

Answer: ____________

Exercise 8: While Miss Levesque is erasing the blackboard with her 9.0×10^{-3}-m^2 eraser, the eraser is subjected to a great amount of shearing force. If a 2.0-cm-thick eraser is pushed with a horizontal force of 1.5 N, displacing the top of the eraser by 5.0 mm, what is the shear modulus of the eraser?

Answer: ____________

Exercise 9: Jorge is running down the newly-waxed school hallway and tries to slide across the floor in his sneakers. The 2.0-cm thick rubber soles each have a cross-sectional area of 0.020 m^2 and are sheared with a force of 15 000 N. a) How much are the shoes displaced horizontally? b) Why does Jorge fall forward? ($S_{rubber} = 5.0 \times 10^9$ N/m^2)

Answer: **a.** ____________

Answer: **b.** ____________

9-3 Liquids

Vocabulary **Hydrostatic Pressure:** The pressure exerted on an object by a column of fluid.

The hydrostatic pressure depends upon the original atmospheric pressure pushing on the surface of the fluid, and upon the fluid's density and height.

The farther an object is located below the surface of the fluid, the greater the pressure acting on it.

hydrostatic pressure =
atmospheric pressure + (density)(acceleration due to gravity)(height)

$$P_h = P_a + Dgh$$

For these exercises, assume that normal atmospheric pressure is 1.01×10^5 Pa.

Recall from Chapter 3 that a pascal (Pa) is equivalent to a newton per square meter (N/m^2).

Archimedes' Principle

According to **Archimedes' principle**, an object completely or partially immersed in a fluid is pushed up by a force that is equal to the weight of the displaced fluid.

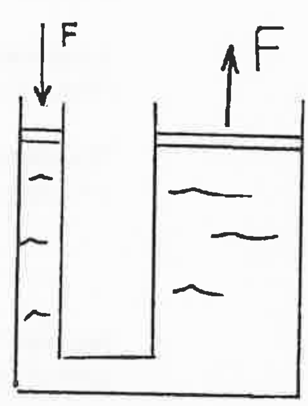
buoyant force = (density)(acceleration due to gravity)(volume)

$$F_b = DgV$$

Here the density and volume are those of the displaced fluid. This equation can be used whether the object sinks or floats. However, if the object is only partially submerged, the volume used in the calculation is that of the submerged portion. Therefore, for a floating object, the buoyant force is equal to the weight of the object itself.

Pascal's Principle

According to **Pascal's principle**, the change in pressure on one part of a confined fluid is equal to the change in pressure on any other part of the confined fluid.



$$\Delta P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

Therefore, a small force exerted over a small area will result in a large force exerted over a large area. An application of Pascal's principle is found in hydraulic lifts, which are used to raise automobiles off the ground. In a hydraulic lift, the force exerted on a smaller piston provides a pressure that is applied, undiminished, to the larger piston, enabling it to lift the car.

Solved Examples

Example 5: Wanda watches the fish in her fish tank and notices that the angel fish like to feed at the water's surface, while the catfish feed 0.300 m below at the bottom of the tank. If the average density of the water in the tank is 1000. kg/m^3, what is the pressure on the catfish?

Solution: Solve this exercise using the equation for hydrostatic pressure.

Given: $P_a = 1.01 \times 10^5$ Pa
$D = 1000.$ kg/m^3
$g = 10.0$ m/s^2
$h = 0.300$ m

Unknown: $P_h = ?$
Original equation: $P_h = P_a + Dgh$

Solve: $P_h = P_a + Dgh = (1.01 \times 10^5 \text{ Pa}) + (1000.\text{ kg/m}^3)(10.0 \text{ m/s}^2)(0.300 \text{ m})$
$= 1.01 \times 10^5 \text{ Pa} + 3.00 \times 10^3 \text{ Pa} = \mathbf{1.04 \times 10^5 \text{ Pa}}$

Example 6: Phyllis is being fed intravenously in her hospital bed from a bottle 0.400 m above her arm that contains a nutrient solution whose density is 1025 kg/m^3. What is the pressure of the fluid that is going into Phyllis' arm?

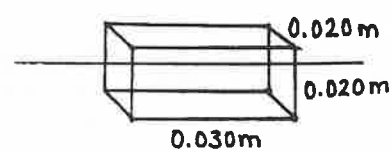
Given: $D = 1025$ kg/m^3
$h = 0.400$ m
$g = 10.0$ m/s^2
$P_a = 1.01 \times 10^5$ Pa

Unknown: $P_a = ?$
Original equation: $P_h + P_a + Dgh$

Solve: $P_h = P_a + Dgh = (1.01 \times 10^5 \text{ Pa}) + (1025 \text{ kg/m}^3)(10.0 \text{ m/s}^2)(0.400 \text{ m})$
$= 1.01 \times 10^5 \text{ Pa} + 4.10 \times 10^3 \text{ Pa} = \mathbf{1.05 \times 10^5 \text{ Pa}}$

Example 7: Palmer drops an ice cube into his glass of water. The ice, whose density is 917 kg/m^3, has dimensions of 0.030 m × 0.020 m × 0.020 m, as shown in the diagram. What is the buoyant force acting on the ice?

Solution: Solve this exercise using Archimedes' principle.



The dimensions of the ice provide you with the ice cube's volume.

$$0.030 \text{ m} \times 0.020 \text{ m} \times 0.020 \text{ m} = 1.2 \times 10^{-5} \text{ m}^3$$

Because the density of the water is less than the ice, the ice will float so that part of it is above the surface. Therefore,

$$\text{buoyant force} = \text{weight of water displaced} = \text{weight of ice}$$

Given: $D_{ice} = 917\ kg/m^3$
$g = 10.0\ m/^2$
$V = 1.2 \times 10^{-5}\ m^3$

Unknown: $F_b = ?$
Original equation: $F_b = DgV$

Solve: $F_b = D_{ice}gV = (917\ kg/m^3)(10.0\ m/s^2)(1.2 \times 10^{-5}\ m^3) = \mathbf{0.11\ N}$

Therefore, the water pushes the ice cube up with a force of 0.11 N.

Example 8: Every Sunday morning, Dad takes the family trash to the trash compactor in the basement. When he presses the button on the front of the compactor, a force of 350 N pushes down on the 1.3-cm² input piston, causing a force of 22 076 N to crush the trash. What is the area of the output piston that crushes the trash?

Solution: Solve this exercise using Pascal's principle.

Given: $F_1 = 350\ N$
$A_1 = 1.3\ cm^2$
$F_2 = 22\ 076\ N$

Unknown: $A_2 = ?$
Original equation: $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

Solve: $A_2 = \frac{F_2 A_1}{F_1} = \frac{(22\ 076\ N)(1.3\ cm^2)}{350\ N} = \mathbf{82\ cm^2}$

Practice Exercises

Exercise 10: The head of a giraffe is 2.0 m above its heart and the density of the blood is $1.05 \times 10^3\ kg/m^3$. What is the difference in pressure between the giraffe's heart and head? (Fortunately, a giraffe's neck has a special circulatory system to adapt to this neck length, producing an even flow of blood to the head.)

Answer: ____________________

Exercise 11: How much pressure is needed in ground-based water pipes to pump water up to the restaurant on the top floor of the World Trade Center, 410 m above the ground?

Answer: ____________________

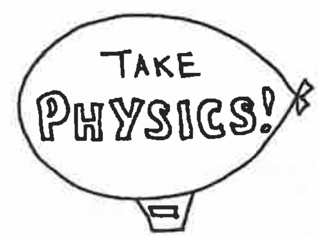
Exercise 12: The difference in pressure between the atmosphere and the human lungs is 1.05×10^5 Pa. What is the longest straw you could use to draw up milk whose density is 1030 kg/m^3?

Answer: ____________________

Exercise 13: Cadir is basting a roast turkey with a meat baster that creates a pressure of 9.980×10^4 Pa when the plastic bulb is squeezed and released. If turkey juice rises 0.0900 m up the tube of the baster, what is the density of the juice?

Answer: ____________________

Exercise 14: A 5450-m^3 blimp circles Fenway Park during the World Series, suspended in Earth's 1.21-kg/m^3 atmosphere. The density of the helium in the blimp is 0.178 kg/m^3. a) What is the buoyant force that suspends the blimp in the air? b) How does this buoyant force compare to the blimp's weight? c) How much weight, in addition to the helium, can the blimp carry and still continue to maintain a constant altitude?

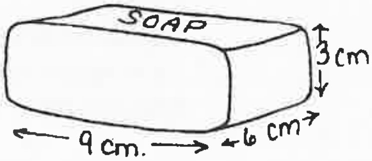


Answer: **a.** ____________________

Answer: **b.** ____________________

Answer: **c.** ____________________

Exercise 15: Ivory soap will float when placed in water so that most of the soap is suspended below the surface, and only a small fraction sticks up above the water line. A bar of soap has dimensions of 9.00 cm × 6.00 cm × 3.00 cm, as shown, and a density of 994 kg/m^3. What is the buoyant force acting on the soap?



Answer: ____________________

Exercise 16: Eliza, the auto mechanic, is raising a 1200.-kg car on her hydraulic lift so that she can work underneath. If the area of the input piston is 12.0 cm^2, while the output piston has an area of 700. cm^2, what force must be exerted on the input piston to lift the car?

Answer: ____________________

Exercise 17: Allegra's favorite ride at the Barrel-O-Fun Amusement Park is the Flying Umbrella, which is lifted by a hydraulic jack. The operator activates the ride by applying a force of 72 N to a 3.0-cm-wide cylindrical piston, which holds the 20 000.-N ride off the ground. What is the diameter of the piston that holds the ride?

Answer: ____________________

9-4 Gases

The **ideal gas law** expresses the relationship between the pressure, volume, and temperature of a gas.

In the exercises in this chapter, the mass of the gas remains constant. You will be examining relationships between changes in pressure, volume, or temperature, using a combined form of the law that reads:

$$\frac{(\textbf{Pressure}_1)(\textbf{Volume}_1)}{\textbf{Temperature}_1} = \frac{(\textbf{Pressure}_2)(\textbf{Volume}_2)}{\textbf{Temperature}_2} \quad \text{or} \quad \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

where the subscript "1" signifies the initial conditions and the subscript "2" signifies the final conditions.

When you do calculations with the ideal gas law, use the correct SI units. Temperature is measured in **kelvins (K)**, pressure is measured in **pascals (Pa)**, and volume is measured in **cubic meters (m^3)**. See Chapter 10 for an explanation of the Kelvin temperature scale.

If the temperature remains constant, the relationship between changes in pressure and volume is known as **Boyle's law.** Boyle's law says that volume decreases as the pressure increases. If the pressure remains constant, the relationship between changes in volume and temperature is known as **Charles' law.** Charles' law says that volume increases as the temperature increases.

Solved Examples

Example 9: To capture its prey, a whale will create a cylindrical wall of bubbles beneath the surface of the water, trapping confused fish inside. If an air bubble has a volume of 5.0 cm^3 at a depth where the water pressure is 2.00×10^5 Pa, what is the volume of the bubble just before it breaks the surface of the water?

Solution: In this exercise, the temperature remains the same. Remove it from both sides of the equation.

Given: $P_1 = 2.00 \times 10^5$ Pa
$V_1 = 5.00$ cm^3
$P_2 = 1.01 \times 10^5$ Pa

Unknown: $V_2 = ?$
Original equation: $P_1V_1 = P_2V_2$

Solve: $$V_2 = \frac{P_1V_1}{P_2} = \frac{(2.00 \times 10^5\ \text{Pa})(5.00\ \text{cm}^3)}{1.01 \times 10^5\ \text{Pa}} = \mathbf{9.90\ cm^3}$$

Example 10: Tootie, a clown, carries a 2.00×10^{-3}-m^3 helium-filled mylar balloon from the 295-K heated circus tent to the cold outdoors, where the temperature is 273 K. How much does the volume of the balloon decrease?

Solution: In this exercise the pressure remains constant. Therefore, remove it from both sides of the equation.

Given: $V_1 = 2.00 \times 10^{-3}\ \text{m}^3$
$T_1 = 295\ \text{K}$
$T_2 = 273\ \text{K}$

Unknown: $V_2 = ?$
Original equation: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Solve: $V_2 = \frac{V_1 T_2}{T_1} = \frac{(2.00 \times 10^{-3}\ \text{m}^3)(273\ \text{K})}{295\ \text{K}} = 1.85 \times 10^{-3}\ \text{m}^3$

$V_1 - V_2 = (2.00 \times 10^{-3}\ \text{m}^3) - (1.85 \times 10^{-3}\ \text{m}^3) = \mathbf{0.15 \times 10^{-3}\ m^3}$

Example 11: Taylor is cooking a pot roast for dinner in a pressure cooker. Water will normally boil at a temperature of 373 K and an atmospheric pressure of 1.01×10^5 Pa. What is the boiling temperature inside the pot, when the pressure is increased to 1.28×10^5 Pa? The pot maintains a constant volume.

Solution: In this example the volume remains constant. Therefore, remove it from both sides of the equation.

Given: $P_1 = 1.01 \times 10^5\ \text{Pa}$
$T_1 = 373\ \text{K}$
$P_2 = 1.28 \times 10^5\ \text{Pa}$

Unknown: $T_2 = ?$
Original equation: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

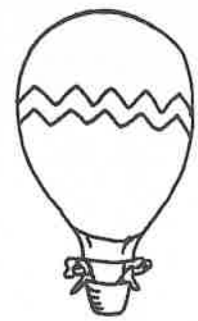
Solve: $T_2 = \frac{P_2 T_1}{P_1} = \frac{(1.28 \times 10^5\ \text{Pa})(373\ \text{K})}{1.01 \times 10^5\ \text{Pa}} = \mathbf{473\ K}$

Practice Exercises

Exercise 18: The Caloric value of food is measured with a device called a bomb calorimeter. Oxygen is forced into this sealed container and kept at a constant volume. Once the internal pressure is increased to 1.50×10^5 Pa, a small piece of food inside the calorimeter is ignited with a spark. As the food burns, the temperature inside the sealed vessel rapidly increases from 293 K to 523 K. What is the new pressure of the gas inside the chamber when the temperature rises?

Answer: ______________________

Exercise 19: Brandon takes Yvonne on a surprise hot-air balloon ride for her birthday. However, once the pair is airborne, Yvonne announces that she is afraid of heights. The 2200.-m^3 balloon is filled to capacity with 350.0 K air at a height where the surrounding air presure is 1.01×10^5 Pa. When Brandon turns off the heating unit, the air in the balloon begins to cool and the balloon descends. a) Why do both the pressure and volume of the air in the balloon remain constant, even though the balloon's air cools to a temperature of 300.0 K? b) Hot-air balloons are always made so that the bottom remains open throughout the flight. By how much would the balloon's volume change if the balloon could be manually closed as the temperature dropped to 300.0 K? (Assume atmospheric pressure remains constant.)



Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 20: During Annette's first airplane ride, her plane ascends from sea level, where cabin pressure is 1.01×10^5 Pa, to flying altitude, where the cabin pressure drops slightly to 1.00×10^5 Pa despite pressurized conditions. Annette feels a sensation in her middle ear, whose volume is 6.0×10^{-7} m^3. a) What is the new volume of air inside Annette's middle ear? b) What could Annette do to compensate for this change in volume?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 21: Theo has won a a new car on a game show, and when his shiny new vehicle arrives on a warm 301-K (28°C) fall day, the 0.016-m^3 tires have an air pressure of 2.02×10^5 Pa. However, two weeks later, when the temperature drops to 273 K (0°C), Theo's pressure gauge reads only 1.90×10^5 Pa. What is the new volume of the car tires?

Answer: ____________________

Additional Exercises

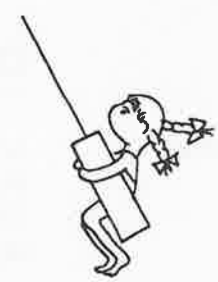
A-1: A 1.9–kg piece of wood from a sunken pirate ship has a volume of 2.16×10^{-3} m^3. Will this piece of wood float to the surface of the water or remain submerged with the ship?

A-2: Ursula drops a 0.0330-kg ice cube into her glass of soda water. The ice cube has dimensions of 3.0 cm $\times$ 3.0 cm $\times$ 4.0 cm. Does the ice cube float or sink in Ursula's drink?

A-3: Which is more dense, a 20.0-g silver bullet that occupies a volume of 1.9 cm^3, or the 5.98×10^{24}-kg Earth, that occupies a volume of 1.08×10^{21} m^3?

A-4: In her gymnastics routine, Regina dismounts from the uneven–parallel bars and lands straight-legged on the ground, compressing her 0.250–m–long femur by 2.10×10^{-5} m. If the femur has a cross-sectional area of 3.00×10^{-4} m^2 and the stress modulus of bone is 2.00×10^{10} N/m^2, with how much force does Regina hit the ground?

A-5: When they go swimming in their favorite water hole, Jeb and Dixie like to swing over the water on an old tire attached to a tree branch with a 3.0-m nylon rope. If the diameter of the rope is 2.00 cm, by how much does the rope stretch when 60.0-kg Dixie swings from it? ($Y_{nylon} = 3.7 \times 10^9$ N/m^2)



A-6: Lucy is going skin diving to see coral off the coast of Mexico in sea water with a density of 1025 kg/m^3. a) How great is the pressure pushing on Lucy at a depth of 20.0 m? b) How will the pressure change if Lucy swims deeper?

A-7: A water tower sits on the top of a hill and supplies water to the citizens below. The difference in pressure between the water tower and the Daileys' house is 1.1×10^5 Pa, while the difference in pressure between the tower and the Stearns' house is 3.2×10^5 Pa. a) Which house sits at a higher elevation, the Daileys' or the Stearns'? b) What is the difference in elevation between the two houses?

A-8: Eileen is floating on her back in the beautiful blue Caribbean during her spring vacation. If Eileen's density is 980 kg/m^3 and she has a volume of 0.060 m^3, what is the buoyant force that supports her in the sea water of density 1025 kg/m^3?

A-9: While swimming in her backyard pool, Nicole attempts to hold a 0.9000-m^3 inner tube completely submerged under the water. a) What buoyant force will be exerted on the inner tube as Nicole attempts to force it under the water? b) When Nicole lets go of the inner tube, it pops up to the surface with a force of 8990. N. What is the weight of the inner tube?

A-10: Irene is testing the strength of her model balsa wood bridge with a hydraulic press before the National Contest in Denver. Irene exerts a force of 3.0 N on a 1-cm-radius input piston, and a force is exerted on the 10.0-cm-radius output piston. If the bridge can withstand a force of 350 N before breaking, will the bridge survive the test and make it into the contest?

A-11: In exercise A-6, if Lucy were to foolishly hold her breath as she ascends to the water's surface, a) by how many times would the volume of her lungs change (assuming the water temperature remains constant)? b) Would her lungs be crushed or would they blow up like a balloon? c) What is the best way to ascend after diving?

A-12: Dong-Jae is bottling his own root beer in his basement where the air temperature is 315 K. The pressure inside each root beer bottle is 1.20×10^5 Pa, but the caps will pop off the bottles if the pressure inside exceeds 1.35×10^5 Pa. After the bottles are sealed and labeled, Dong-Jae stores them in his attic, which heats up to 364 K on a hot summer day. What happens to the pressure inside the bottles?

Challenge Exercises for Further Study

B-1: A 40.0-m-long steel elevator cable has a cross-sectional area of 4.0×10^{-4} m^2 and is able to stretch 1.0 cm before breaking. If the elevator itself has a mass of 1000. kg, how many 70.0-kg people can safely ride in the elevator? ($Y_{steel} = 2.0 \times 10^{11}$ N/m^2)

B-2: A can of soda displaces 3.79×10^{-4} m^3 of water when completely submerged. Each 0.018-kg can contains 3.54×10^{-4} m^3 of soda. a) Compare the buoyant force on a can of diet soda of density 1001 kg/m^3 to the force on a can of regular soda of density 1060. kg/m^3. b) If many cans of diet and regular soda are in a large tub of water and ice, how can you easily pick out the diet soda?

B-3: Saul ascends from the city of Tucson, Arizona, to the top of Kitt Peak, 2900 m above sea level. Usually Saul will feel his ears "pop" as the pressure inside his ears attempts to maintain equilibrium with the surrounding air. However, on this day Saul has a cold and his Eustachian tube is clogged, causing a tremendous pressure behind his 4.0×10^{-5}-m^2 ear drum. a) What force does Saul feel pushing on his ears? b) Is this pressure pushing in or out of his ear as he ascends? ($D_{air} = 1.20$ kg/m^3)

B-4: Hannah and her friends go fishing in her 1.20-m^3 rowboat, which has a mass of 100. kg. How many 60.0-kg people can get into the boat before the boat sinks?

10 Temperature and Heat

10-1 Temperature and Expansion

Vocabulary **Temperature:** A quantity that you can measure with a thermometer.

There are many different scales for measuring the temperature of an object. The SI unit for temperature is the **kelvin (K)**. The Kelvin scale is based on absolute zero, a point at which the internal movement of an object's atoms or molecules is a minimum and no heat can be removed. An increase of one kelvin on the Kelvin scale is equal to an increase of one degree Celsius on the Celsius scale. Respectively, the freezing and boiling temperatures of water on these two scales are 0°C = 273 K and 100°C = 373 K.

Notice that the Kelvin scale does not use the degree symbol, °. We say, "Zero degrees Celsius equals two hundred seventy-three kelvins."

However, the Fahrenheit scale is most common on household thermometers. Degrees Fahrenheit can be changed to degrees Celsius by writing.

$$T_C = \frac{5}{9}(T_F - 32.0)$$

Degrees Celsius can be changed to degrees Fahrenheit by writing

$$T_F = \left(\frac{9}{5}T_C\right) + 32.0$$

Heating an object will generally make its atoms or molecules move faster and cause the object to increase in size.

Linear Expansion

When a solid object experiences a temperature change, its length will increase by a certain amount depending upon the nature of the material.

change in length =

(original length)(coefficient of expansion)(change in temperature)

or $\Delta L = L_o \alpha \Delta T$

where α, the **coefficient of linear expansion**, is a characteristic property of the material. The SI unit for the coefficient of linear expansion is **°C^{-1}** (which is the same as 1/°C).

Area Expansion

An object may also expand in area when heated. The equation for area expansion is

change in area =

2(original area)(coefficient of expansion)(change in temperature)

or $\Delta A = 2A_0\alpha\Delta T$

Volume Expansion

If the volume of a solid or liquid expands, the equation is written as

change in volume =

(original volume)(coefficient of expansion)(change in temperature)

or $\Delta V = V_0\beta\Delta T$

where β is the coefficient of volume expansion.

Solved Examples

Example 1: Justin is trying to convince his mother that he has a fever and should stay home from school. However, he has a thermometer that will measure his temperature in degrees Celsius. If Justin's temperature is 39.0°C and "normal" is 98.6°F, is Justin's temperature high enough to keep him home?

Given: $T_C = 39.0°C$

Unknown: $T_F = ?$

Original equation: $T_F = \left(\frac{9}{5}T_C\right) + 32.0$

Solve: $T_F = \left(\frac{9}{5}T_C\right) + 32.0 = \frac{9}{5}(39.0°C) + 32.0 = \mathbf{102°F}$

Yes. He should stay home.

Example 2: The layer of the sun that we see is called the photosphere. It has a temperature of 5600 K. What is the sun's temperature a) in degrees Celsius? b) in degrees Fahrenheit?

a. *Given:* $T_K = 5600$ K

Unknown: $T_C = ?$

Original equation: $T_C = T_K - 273$

Solve: $T_C = T_K - 273 = 5600 - 273 = \mathbf{5327°C}$

b. *Given:* $T_C = 5327°C$

Unknown: $T_F = ?$
Original equation: $T_F = \left(\frac{9}{5}T_C\right) + 32.0$

Solve: $T_F = \left(\frac{9}{5}T_C\right) + 32.0 = \frac{9}{5}(5327°C) + 32.0 = \mathbf{9621°F}$ Pretty hot!

Example 3: Ernesto is knitting his wife a sweater in his 18°C air-conditioned living room with 0.30-m-long aluminum knitting needles, when he decides to knit outside in the 27°C air. How much will the knitting needles expand when Ernesto takes them outside? ($\alpha_{aluminum} = 24 \times 10^{-6}\,°C^{-1}$)

Given: $L_o = 0.30$ m
$\alpha = 24 \times 10^{-6}\,°C^{-1}$
$T_o = 18°C$
$T_f = 27°C$

Unknown: $\Delta L = ?$
Original equation: $\Delta L = L_o\alpha\Delta T$

Solve: $\Delta L = L_o\alpha\Delta T = L_o\alpha(T_f - T_o) = (0.30\text{ m})(24 \times 10^{-6}\,°C^{-1})(27°C - 18°C)$
$= \mathbf{6.5 \times 10^{-5}\ m}$

Example 4: Jacques, the French chef, is kneading the dough for French bread in his 21°C kitchen. He places the dough on a 0.40-m × 0.60-m aluminum cookie sheet. If the oven temperature is 177°C, how much does the cookie sheet expand in area while it is in the oven? ($\alpha_{aluminum} = 24 \times 10^{-6}\,°C^{-1}$)

Solution: Because the cookie sheet will expand in two directions, it is necessary to use the equation for area expansion. The area of the cookie sheet is 0.40 m × 0.60 m = 0.24 m^2.

Given: $A_o = 0.24\text{ m}^2$
$\alpha = 24 \times 10^{-6}\,°C^{-1}$
$T_o = 21°C$
$T_f = 177°C$

Unknown: $\Delta A = ?$
Original equation: $\Delta A = 2A_o\alpha\Delta T$

Solve: $\Delta A = 2A_o\alpha\Delta T = 2(0.24\text{ m}^2)(24 \times 10^{-6}\,°C^{-1})(177°C - 21°C)$
$= \mathbf{0.0018\ m^2}$

Example 5: A thermometer contains 0.50 cm^3 of mercury at room temperature (21°C) when Pilar takes it into the physics lab for an experiment. By how much does the volume of mercury in the thermometer change after it sits in an 80.°C beaker of water? ($\beta_{mercury} = 18 \times 10^{-5}\,°C^{-1}$)

Given: $V = 0.50\text{ cm}^3$
$\beta_{mercury} = 18 \times 10^{-5}\,°C^{-1}$
$T_o = 21°C$
$T_f = 80.°C$

Unknown: $\Delta V = ?$
Original equation: $\Delta V = V_o\beta\Delta T$

Solve: $\Delta V = V_o\beta\Delta T = V_o\beta(T_f - T_o) = (0.50\text{ cm}^3)(18 \times 10^{-5}\,°C^{-1})(80.°C - 21°C)$
$= \mathbf{0.0053\ cm^3}$

Practice Exercises

Exercise 1: On a summer day at the equator on Mars, the temperature never rises higher than 50.0°C. Find this temperature in degrees Fahrenheit in order to determine if this would be a comfortable temperature for a human visiting Mars.

Answer: ____________________

Exercise 2: The highest temperature ever recorded on Earth was 136.4°F at Al' Aziziyah, Libya, on September 13, 1922. The lowest temperature ever recorded was −128.6°F at Vostok, Antarctica, on July 22, 1983. Calculate both of these temperatures in degrees Celsius.

Answer: ____________________

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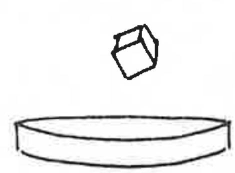
Exercise 3: The barium-yttrium ceramic compound used to demonstrate superconductivity will work only if supercooled to a temperature of 125 K. What is the equivalent temperature a) in °C? b) in °F?



Answer: ____________________

Exercise 4: Most bridges contain interlocking grates that allow the bridge to expand and contract with the change in temperature. The Golden Gate Bridge in San Francisco is about 1350 m long. a) The seasonal temperature variation in San Francisco ranges from about 0°C to 30.°C. How much will the bridge expand between these extremes? ($\alpha_{steel} = 12 \times 10^{-6}\,°C^{-1}$) b) Approximately how wide is this gap compared to the length of an automobile?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 5: Selena has a fire in the fireplace to warm her 20.°C apartment. She realizes that she has left the iron poker in the fire. How hot is the fire if the 0.60-m poker lengthens 0.30 cm? ($\alpha_{iron} = 12 \times 10^{-6}\,°C^{-1}$)

Answer: ____________________

Exercise 6: Leila is building an aluminum-roofed shed in her backyard to store her garden tools. The flat roof will measure 2.0 m × 3.0 m in area during the coldest winter months when the temperature is −10°C, but temperatures in Leila's neighborhood can reach as high as 38°C in the summer. What is the area of the roof that should stick out from the shed in the summer so that the roof just fits the structure during cold winter nights?
($\alpha_{aluminum} = 24 \times 10^{-6}\,°C^{-1}$)

Answer: ____________________

Exercise 7: Just before midnight, when the air temperature is 10.0°C, Karl stops and fills the 0.0600-m^3 gas tank of his car. At noon the next day, when the temperature has risen to 32.0°C, Karl finds a puddle of gasoline beneath his car. a) What do you think happened? b) How much gasoline spilled out of Karl's car (assuming no change in the volume of the tank)? ($\beta_{gasoline} = 3.00 \times 10^{-4}\,°C^{-1}$)

Answer: **a.** ____________________

Answer: **b.** ____________________

10-2 Heat

Vocabulary **Heat:** The transfer of energy between two objects that differ in temperature.

Vocabulary **Specific heat:** A measure of the amount of heat needed to raise the temperature of 1 kg of a substance by 1°C.

The common unit for specific heat is the **joule per kilogram degree celsius (J/kg°C).**

The transfer of heat from an object depends upon the object's mass, the specific heat, and the difference in temperature between the object and its surroundings.

change in heat = (mass)(specific heat)(change in temperature)

or $\Delta Q = mc\Delta T$

The SI unit for heat is the **joule (J).** This is the same unit used for mechanical energy in Chapter 5.

The heat lost by one object equals the heat gained by another object.

Heat lost = Heat gained or $(mc\Delta T)_{lost} = (mc\Delta T)_{gained}$

For each object in the system, an $mc\Delta T$ term is needed.

Water has a very high specific heat. It makes a good cooling agent because it takes a long time for water to absorb enough heat to greatly increase its temperature. In the following exercises, you will need to know the specific heat of water and of ice.

$$c_{water} = 4187\ \mathrm{J/kg°C} \qquad c_{ice} = 2090\ \mathrm{J/kg°C}$$

All other values for specific heat will be given in the exercises.

Heat of Fusion

Vocabulary

Heat of Fusion: The quantity of heat needed per kilogram to melt a solid (or solidify a liquid) at a constant temperature and atmospheric pressure.

The amount of heat needed to melt a solid is

change in heat = (mass)(heat of fusion) or $\Delta Q = mh_f$

The SI unit for the heat of fusion is the **joule per kilogram (J/kg).**

For water, which will be used most frequently in the exercises, the heat of fusion is **3.35×10^5 J/kg.** This means that 3.35×10^5 J of heat is required to turn 1 kg of ice into water. The same amount of heat is given off when 1 kg of water turns into ice.

Heat of Vaporization

Vocabulary

Heat of Vaporization: The quantity of heat needed per kilogram to vaporize a liquid (or liquify a gas) at a constant temperature and atmospheric pressure.

The amount of heat needed to vaporize a liquid is

change in heat = (mass)(heat of vaporization) or $\Delta Q = mh_v$

The SI unit for the heat of vaporization is the **joule per kilogram (J/kg).**

For water, the heat of vaporization is **2.26×10^6 J/kg.** This is more than six times the heat of fusion for water.

Note that "steam" is not the same thing as water vapor. Water vapor is an invisible gas that results when water boils or evaporates. Steam is what you see when water vapor is cooled and condenses back into water droplets.

Solved Examples

Example 6: Hypothermia can occur if the body temperature drops to 35.0°C, although people have been known to survive much lower temperatures. On January 19, 1985, 2-year-old Michael Trode was found in the snow near his Milwaukee home with a body temperature of 16.0°C. If Michael's mass was 10.0 kg, how much heat did his body lose, assuming his normal body temperature was 37.0°C? ($c_{\text{human body}} = 3470\ \text{J/kg°C}$)

Given: $m = 10.0\ \text{kg}$
$c = 3470\ \text{J/kg°C}$
$T_f = 16.0°\text{C}$
$T_o = 37.0°\text{C}$

Unknown: $\Delta Q = ?$
Original equation: $\Delta Q = mc\Delta T$

Solve: $\Delta Q = mc\Delta T = mc(T_f - T_o) = (10.0\ \text{kg})(3470\ \text{J/kg°C})(16.0°\text{C} - 37.0°\text{C})$
$= \mathbf{-729\ 000\ J}$

The negative answer implies that there was a heat loss. The encouraging (and amazing) end to this example is that Michael survived!

Example 7: Gwyn's bowl is filled with 0.175 kg of 60.0°C soup (mostly water) that she stirs with a 20.0°C silver spoon of mass 0.0400 kg. The spoon slips out of her hand and slides into the soup. What equilibrium temperature will be reached if the spoon is allowed to remain in the soup and no heat is lost to the outside air? ($c_{\text{spoon}} = 240.\ \text{J/kg°C}$) Assume that the temperature of the bowl does not change.

Given: $m_{\text{water}} = 0.175\ \text{kg}$
$c_{\text{water}} = 4187\ \text{J/kg°C}$
$T_{\text{water}} = 60.0°\text{C}$
$m_{\text{spoon}} = 0.0400\ \text{kg}$
$c_{\text{spoon}} = 240.\ \text{J/kg°C}$
$T_{\text{spoon}} = 20.0°\text{C}$

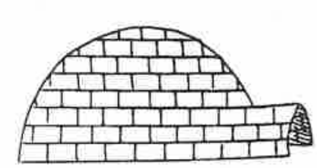
Unknown: $T_f = ?$
Original equation: Heat lost = Heat gained

Solve: $mc\Delta T_{\text{water}} = mc\Delta T_{\text{spoon}}$

$$(0.175\ \text{kg})(4187\ \text{J/kg°C})(60.0°\text{C} - T_f) = (0.0400\ \text{kg})(240.\ \text{J/kg°C})(T_f - 20.0°\text{C})$$
$$43\ 963\ \text{J} - (732.7\ T_f)\text{J/°C} = (9.6\ T_f)\text{J/°C} - 192\ \text{J}$$
$$44\ 155\ \text{J} = (742.3\ T_f)\text{J/°C}$$
$$T_f = \frac{44\ 155\ \text{J}}{742.3\ \text{J/°C}} = \mathbf{59.5°C}$$

Therefore, the temperature of the spoon and soup both reach equilibrium at 59.5°C, so the spoon has become much hotter but the soup has only cooled by 0.5°C.

Example 8: An igloo is made of 224 blocks of ice at 0°C, each with a mass of 12.0 kg. How much heat must be gained by the ice to melt the entire igloo?



Solution: The total mass of the ice is 224 (12.0 kg) = 2690 kg

Given: $m = 2690$ kg
$h_f = 3.35 \times 10^5$ J/kg

Unknown: $\Delta Q = ?$
Original equation: $\Delta Q = mh_f$

Solve: $\Delta Q = mh_f = (2690 \text{ kg})(3.35 \times 10^5 \text{ J/kg}) = \mathbf{9.01 \times 10^8 \text{ J}}$

Example 9: Gus is cooking soup in his hot pot and finds that he has added too much water. If Gus needs to boil off 0.200 kg of water in order for his soup to have the correct consistency, how much additional heat must Gus add once the soup is boiling?

Given: $m = 0.200$ kg
$h_v = 2.26 \times 10^6$ J/kg

Unknown: $\Delta Q = ?$
Original equation: $\Delta Q = mh_v$

Solve: $\Delta Q = mh_v = (0.200 \text{ kg})(2.26 \times 10^6 \text{ J/kg}) = \mathbf{4.52 \times 10^6 \text{ J}}$

Example 10: To cool her 0.200-kg cup of 75.0°C hot chocolate (mostly water), Heidi drops a 0.0300-kg ice cube at 0°C into her insulated foam cup. What is the temperature of the hot chocolate after all the ice is melted?

Solution: The relationship "Heat lost = Heat gained" can take on many forms depending upon what is happening in the exercise. In this exercise, heat is lost from the hot chocolate ($mc\Delta T_{water}$) and gained by the ice cube, first melting it (mh_f) and then raising its temperature ($mc\Delta T_{water}$).

Given: $m_{ice} = 0.0300$ kg
$m_{water} = 0.200$ kg
$h_f = 3.35 \times 10^5$ J/kg
$c_{water} = 4187$ J/kg°C
$T_{water} = 75.0°C$
$T_{ice} = 0°C$

Unknown: $T_f = ?$
Original equation: Heat lost = Heat gained

Solve: $mc\Delta T_{water} = mh_{f(ice)} + mc\Delta T_{water} = (0.200 \text{ kg})(4187 \text{ J/kg°C})(75.0°C - T_f)$

$= (0.0300 \text{ kg})(3.35 \times 10^5 \text{ J/kg}) + (0.0300 \text{ kg})(4187 \text{ J/kg°C})(T_f - 0°C)$

$= 62\,805 \text{ J} - (837.4\, T_f)\text{J/°C} = 10\,050 \text{ J} + 125.6\, T_f(\text{J/°C})$

$= 52\,755 \text{ J} = (963.0\, T_f)\text{J/°C}$ so $T_f = \dfrac{52\,755 \text{ J}}{963.0 \text{ J/°C}} = \mathbf{54.8°C}$

Practice Exercises

Exercise 8: Peter is heating water on the stove to boil eggs for a picnic. How much heat is required to raise the temperature of his 10.0-kg vat of water from 20.0°C to 100.0°C?

Answer: ____________________

Exercise 9: Nova, whose mass is 50.0 kg, stays out skiing for too long and her body temperature drops by 2.00°C. What is the amount of heat lost from Nova's body? ($c_{\text{human body}} = 3470 \text{ J/kg°C}$)

Answer: ____________________

Exercise 10: Phoebe's insulated foam cup is filled with 0.150 kg of the coffee (mostly water) that is too hot to drink, so she adds 0.010 kg of milk at 5.0°C. If the coffee has an initial temperature of 70.0°C and the specific heat of milk is 3800 J/kg°C, how hot is the coffee after the milk is added? (Assume that no heat leaks out through the cup.)

Answer: ____________________

Exercise 11: Emily is testing her baby's bath water and finds that it is too cold, so she adds some hot water from a kettle on the stove. If Emily adds 2.00 kg of water at 80.0°C to 20.0 kg of bath water at 27.0°C, what is the final temperature of the bath water?

Answer: ____________________

Exercise 12: Finishing his ginger ale, Ramesh stands at a party holding his insulated foam cup that has nothing in it but 0.100 kg of ice at 0°C. How much heat must be gained by the ice in order for all of it to melt?

Answer: ____________________

Exercise 13: In Exercise 12, how much more heat must be gained to raise the temperature of the melted ice to room temperature of 23.0°C?

Answer: ____________________

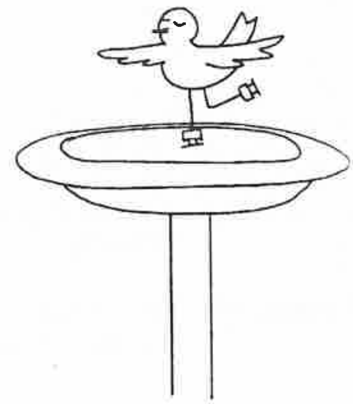
Exercise 14: Under the spreading chestnut tree the village blacksmith dunks a red-hot horseshoe into a large bucket of 22.0°C water. How much heat was lost by the horseshoe in vaporizing 0.0100 kg of water?

Answer: ____________________

Exercise 15: While Laurie is boiling water to cook spaghetti, the phone rings, and all 1.5 kg of water boils away during her conversation. If the water was initially at 15°C, how much heat must have been gained for all of it to turn into water vapor?

Answer: ____________________

Exercise 16: By January, the 3.0 kg of water in the birdbath in Robyn's backyard has frozen to a temperature of −7.0°C. As the season changes, how much heat must be added to the water to make it a comfortable 25°C for the birds?



Answer: ____________________

Additional Exercises

A-1: The hottest temperature on a planet was 864°F recorded on Venus by the Soviet *Venera* probe and the U.S. *Pioneer* probe. The coldest place in the solar system is Pluto where the temperature is estimated at −360.0°F. Calculate each of these temperatures in degrees Celsius.

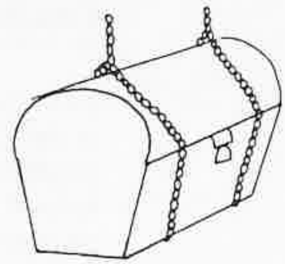
A-2: The temperature of background radiation left over from the Big Bang during the creation of the universe is 3 K. What is the temperature of the universe a) in °C? b) in °F?

A-3: As he rides the train to work on a −4.0°C winter day, Mr. Trump notices that he can hear the click of the train going over spaces between the rails. Six months later, on a 30.0-°C summer day, the rails are pushed tightly together and he hears no click. If the rails are 5.00 m long, how large a gap is left between the rails on the cold winter day? ($\alpha_{steel} = 12 \times 10^{-6}\,°C^{-1}$)

A-4: Bradley, working in his 23°C kitchen, is cooking himself a crepe in an iron skillet that has a circular bottom with a diameter of 30.00 cm. How hot must the skillet be in order for Bradley to make a 710.3-cm^2 crepe that just fills the bottom of the pan? ($\alpha_{iron} = 12 \times 10^{-6}\,°C^{-1}$)

A-5: A popular winter activity of many college students is "traying," or sliding down a snow-covered hill on a tray borrowed from the dining hall. If Joanne removes a 0.35-m × 0.65-m aluminum tray from the 20.°C dining hall to go traying in the brisk −8°C winter air, how much will the tray shrink when taken outside? ($\alpha_{aluminum} = 24 \times 10^{-6}\,°C^{-1}$)

A-6: A 0.50-m^3 brass treasure chest is pulled out of the cold 15°C ocean and onto the deck of a ship, where the air temperature is 40°C. How much does the volume of the treasure chest expand? ($\beta_{brass} = 56 \times 10^{-6}\,°C^{-1}$)



A-7: Leslie takes a full bottle of benzene from the 25.0°C chemistry lab into the 10.0°C refrigerated storage locker. Later, Leslie enters the storage locker and finds that 37.0 cm^3 of benzene is missing from the bottle. What was the original volume of benzene in the bottle? ($\beta_{benzene} = 1240 \times 10^{-6}\,°C^{-1}$)

A-8: Sidney is home from school with a cold, so Mom has made him a bowl of chicken soup (mostly water), which she ladles from a pot into a glass bowl. If 0.600 kg of soup at 90.0°C is placed in a 0.200-kg bowl that is initially at 20.0°C, what will be the temperature of the soup when the bowl and soup have reached equilibrium? (c_{glass} = 840. J/kg°C)

A-9: In A-8 above, when the soup and bowl are at 80.0°C, a chilled dumpling with a mass of 0.100 kg and a temperature of 10.0°C is added. What will be the temperature of the dumpling, soup, and bowl when the three have reached equilibrium? ($c_{dumpling}$ = 110. J/kg°C)

A-10: Nils is emptying the dishwasher. He removes a 0.200-kg glass that has a temperature of 30.0°C. Into it he pours 0.100 kg of diet soda (mostly water), which comes out of the refrigerator with a temperature of 5.00°C. Assuming no external heat loss, what will be the final equilibrium temperature of the glass of diet soda? (c_{glass} = 840. J/kg°C)

A-11: In Exercise A-10, Nils doesn't feel that his drink is cold enough, so he throws in an ice cube whose temperature is −3.0°C. What is the mass of the ice cube if his drink (and glass) are now cooled to 1.0°C?

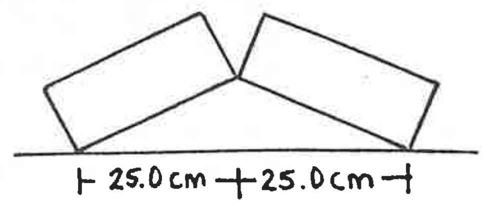
A-12: A puddle filled with 20. kg of water is completely frozen to −6.0°C in the middle of the winter. How much heat must be absorbed by the puddle to melt the ice and warm the water up to 20.°C during the spring thaw?

A-13: Before ironing his shirt for work, Nathaniel drops some water on his iron to test whether it is hot enough to iron his clothes. How much heat is needed to vaporize a 5.0×10^{-4}-kg drop of 20.°C water?

Challenge Exercises for Further Study

B-1: Lawrence, a civil engineer, uses a steel tape measure to figure the dimensions of the Emersons' property. When the temperature is 37°C, he determines the property line to be 152.000 m long. However, the length of the property seems to have changed when Lawrence returns on a 5.0°C winter day. a) Does the property appear to be longer in the warm weather or the cold? Explain why you think this is so. b) How long is the property when measured by his steel tape in the winter? ($\alpha_{steel} = 12 \times 10^{-6}\,°C^{-1}$)

B-2: One cool 5.0°C spring morning, Mason lays a brick sidewalk up to his house, placing the 25.0-cm-long bricks end to end against each other. However, Mason forgets to leave a space for expansion and when the temperature reaches 36.0°C, the bricks buckle. How high will the bricks rise? ($\alpha_{brick} = 10.0 \times 10^{-6}\,°C^{-1}$)



B-3: Phil is making a sandwich and he is having trouble getting the lid off the jar of mayonnaise. a) If the steel lid and the glass jar each have a diameter of 10. cm at a room temperature of 21°C, should Phil run the lid under water that is 20.°C warmer or 20.°C cooler to remove the lid? b) When he completes the correct procedure to free the lid, what is the size of the space between the lid and the jar? ($\alpha_{aluminum} = 24 \times 10^{-6}\,°C^{-1}$ and $\alpha_{glass} = 8.5 \times 10^{-6}\,°C^{-1}$)

B-4: Pablo brings a 6000.-cm^3 aluminum can filled all the way to the top with turpentine up from the 20.0°C basement and sets it outside where he is painting. The noonday sun heats the turpentine and the aluminum container to 45.0°C. Will the turpentine overflow the container? If so, how much will spill out? If not, how much more could be added to the empty space created? ($\beta_{aluminum} = 77 \times 10^{-6}\,°C^{-1}$ and $\beta_{turpentine} = 900. \times 10^{-6}\,°C^{-1}$)

B-5: In a physics experiment, a 0.100-kg aluminum calorimeter cup holding 0.200 kg of ice is removed from a freezer, where both ice and cup have been cooled to −5.00°C. Next, 0.0500 kg of steam at 100.°C is added to the ice in the cup. What will be the equilibrium temperature of the system after the ice has melted? ($c_{aluminum} = 920.\ J/kg°C$)