The Language of Physics

Temperature
The simplest definition of temperature is that temperature is a measure of the hotness or coldness of a body. A better definition is that temperature is a measure of the mean kinetic energy of the molecules of the body (p. 403).

Thermometer
A device for measuring the temperature of a body (p. 404).

Celsius temperature scale
A temperature scale that uses 0° for the melting point of ice and 100° for the boiling point of water (p. 404).

Fahrenheit temperature scale
A temperature scale that uses 32° for the melting point of ice and 212° for the boiling point of water (p. 405).

Kelvin temperature scale
The absolute temperature scale. The lowest temperature attainable is absolute zero, the 0 K of this scale. The temperature for the melting point of ice is 273 K and 373 K for the boiling point of water (p. 405).

Internal energy
The sum of the potential and kinetic energy of all the molecules of a body (p. 408).

Heat
The flow of thermal energy from a body at a higher temperature to a body at a lower temperature. When a body cools, its internal energy is decreased; when it is heated, its internal energy is increased (p. 408).

Thermal equilibrium
Whenever two bodies at different temperatures are touched together, thermal energy always flows from the hotter body to the cooler body until they are both at the same temperature. When this occurs the two bodies are said to be in thermal equilibrium (p. 408).

Kilocalorie
A unit of heat. It is defined as the amount of thermal energy required to raise the temperature of 1 kg of water 1 °C (p. 408).

British thermal unit (Btu)
The amount of thermal energy required to raise the temperature of 1 lb of water 1 °F (p. 408).

Mechanical equivalent of heat
The equivalence between mechanical energy and thermal energy. One kcal is equal to 4186 J (p. 408).

Specific heat
A characteristic of a material. It is defined as the number of kilocalories required to raise the temperature of 1 kg of the material 1 °C (p. 409).

Calorimetry
The measurement of heat (p. 411).

Calorimeter
An instrument that is used to make measurements of heat. The basic principle underlying the calorimeter is the conservation of energy. The thermal energy lost by those bodies that lose thermal energy is equal to the thermal energy gained by those bodies that gain thermal energy (p. 411).

Phases of matter
Matter exists in three phases, the solid phase, the liquid phase, and the gaseous phase (p. 413).

Change of phase
The change in a body from one phase of matter to another. As an example, melting is a change from the solid state of a body to the liquid state. Boiling is a change in state from the liquid state to the gaseous state (p. 413).

Latent heat of fusion
The amount of heat necessary to convert 1 kg of the solid to 1 kg of the liquid (p. 414).

Latent heat of vaporization
The amount of heat necessary to convert 1 kg of the liquid to 1 kg of the gas (p. 414).

Summary of Important Equations

Convert Fahrenheit temperature to Celsius
$$t\ °C = \tfrac{5}{9}(t\ °F - 32°) \qquad (14.1)$$

Convert Celsius temperature to Fahrenheit
$$t\ °F = \tfrac{9}{5}t\ °C + 32° \qquad (14.2)$$

Convert Celsius temperature to Kelvin
$$T\ K = t\ °C + 273 \qquad (14.4)$$

Thermal energy absorbed or liberated
$$Q = mc\Delta t \qquad (14.6)$$

Principle of calorimetry
Thermal energy lost = Thermal energy gained (14.7)

Fusion
$$Q_f = m_i L_f \qquad (14.15)$$

Vaporization
$$Q_v = m_w L_v \qquad (14.16)$$

Questions for Chapter 14

1. What is the difference between temperature and heat?
2. Explain how a bathtub of water at 5 °C can contain more thermal energy than a cup of coffee at 95 °C.
3. Discuss how the human body uses the latent heat of vaporization to cool itself through the process of evaporation.
†4. Relative humidity is defined as the percentage of the amount of water vapor in the air to the maximum amount of water vapor that the air can hold at that temperature. Discuss how the relative humidity affects the process of evaporation in general and how it affects the human body in particular.
†5. It is possible for a gas to go directly to the solid state without going through the liquid state, and vice versa. The process is called *sublimation.* An example of such a process is the formation of frost. Discuss the entire process of sublimation, the latent heat involved, and give some more examples of the process.
†6. Why does ice melt when an object is placed upon it? Describe the process of ice skating from the pressure of the skate on the ice.
7. Why are the numerical values of the specific heat the same in SI units and British engineering units?

Problems for Chapter 14

14.1 Temperature

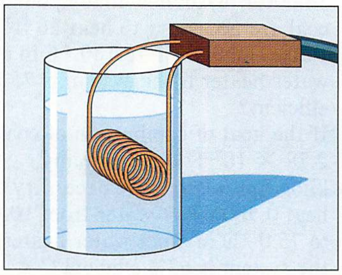
1. Convert the following normal body temperatures to degrees Celsius: (a) oral temperature of 98.6 °F, (b) rectal temperature of 99.6 °F, and (c) axial (armpit) temperature of 97.6 °F.
2. Find the value of absolute zero on the Fahrenheit scale.
3. For what value is the Fahrenheit temperature equal to the Celsius temperature?
4. Convert the following temperatures to Fahrenheit: (a) 38.0 °C, (b) 68.0 °C, (c) 250 °C, (d) −10.0 °C, and (e) −20.0 °C.
5. Convert the following Fahrenheit temperatures to Celsius: (a) −23.0 °F, (b) 12.5 °F, (c) 55.0 °F, (d) 90.0 °F, and (e) 180 °F.
6. A temperature change of 5 °F corresponds to what temperature change in Celsius degrees?

†7. Derive an equation to convert the temperature in Fahrenheit degrees to its corresponding Kelvin temperature.

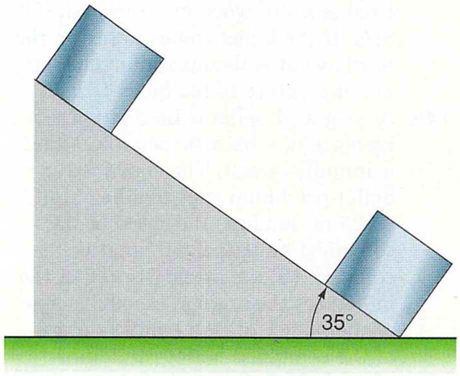
†8. Derive an equation to convert the change in temperature in Celsius degrees to a change in temperature in Fahrenheit degrees.

14.3 Specific Heat

9. A 450-g ball of copper at 20.0 °C is placed in a pot of boiling water until equilibrium is reached. How much thermal energy is absorbed by the ball?
10. A 250-g glass marble is taken from a freezer at −23.0 °C and placed into a beaker of boiling water. How much thermal energy is absorbed by the marble?
11. How much thermal energy must be supplied by an electric immersion heater if you wish to raise the temperature of 5.00 kg of water from 20.0 °C to 100 °C?



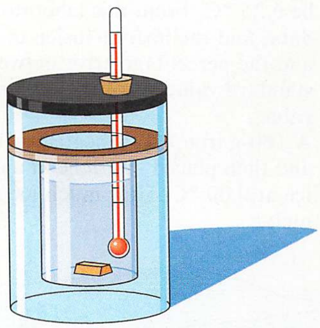
12. A 2.00-kg mass of copper falls from a height of 3.00 m to an insulated floor. What is the maximum possible temperature increase of the copper?
13. An iron block slides down an iron inclined plane at a constant speed. The plane is 10.0 m long and is inclined at an angle of 35.0° with the horizontal. Assuming that half the energy lost to friction goes into the block, what is the difference in temperature of the block from the top of the plane to the bottom of the plane?



14. A 2000-kg car is traveling at 96.6 km/hr when it is braked to a stop. What is the maximum possible thermal energy generated in the brakes?
15. How much thermal energy is absorbed by an aluminum ball 20.0 cm in diameter, initially at a temperature of 20.0 °C, if it is placed in boiling water?

14.4 Calorimetry

16. If 30.0 g of water at 5.00 °C are mixed with 50.0 g of water at 70.0 °C and 25.0 g of water at 100 °C, find the resultant temperature of the mixture.
17. If 80.0 g of lead shot at 100 °C is placed into 100 g of water at 20.0 °C in an aluminum calorimeter of 60.0-g mass, what is the final temperature?
18. A 100-g mass of an unknown material at 100 °C is placed in an aluminum calorimeter of 60.0 g that contains 150 g of water at an initial temperature of 20.0 °C. The final temperature is observed to be 21.5 °C. What is the specific heat of the substance and what substance do you think it is?



19. A 100-g mass of an unknown material at 100 °C, is placed in an aluminum calorimeter of 60.0-g mass that contains 150 g of water at an initial temperature of 15.0 °C. At equilibrium the final temperature is 19.5 °C. What is the specific heat of the material and what material is it?
20. How much water at 50.0 °C must be added to 60.0 kg of water at 10.0 °C to bring the final mixture to 20.0 °C?

†21. A 100-g aluminum calorimeter contains 200 g of water at 15.0 °C. If 100.0 g of lead at 50.0 °C and 60.0 g of copper at 60.0 °C are placed in the calorimeter, what is the final temperature in the calorimeter?

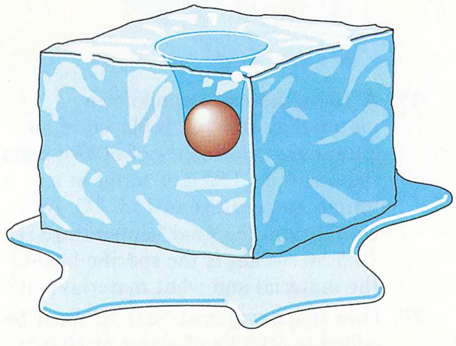
22. A 200-g piece of platinum is placed inside a furnace until it is in thermal equilibrium. The platinum is then placed in a 100-g aluminum calorimeter containing 400 g of water at 5.00 °C. If the final equilibrium temperature of the water is 10.0 °C, find the temperature of the furnace.

14.5 Change of Phase

23. How many calories are needed to change 50.0 g of ice at −10.0 °C to water at 20.0 °C?
24. If 50.0 g of ice at 0.0 °C are mixed with 50.0 g of water at 80.0 °C what is the final temperature of the mixture?
25. How much ice at 0 °C must be mixed with 50.0 g of water at 75.0 °C to give a final water temperature of 20 °C?
26. If 50.0 g of ice at 0.0 °C are mixed with 50.0 g of water at 20.0 °C, what is the final temperature of the mixture? How much ice is left in the mixture?
27. How much heat is required to convert 10.0 g of ice at −15.0 °C to steam at 105 °C?
28. In the laboratory, 31.0 g of ice at 0 °C is placed into an 85.0-g copper calorimeter cup that contains 155 g

of water at an initial temperature of 23.0 °C. After the ice melts, the final temperature of the water is found to be 6.25 °C. From this laboratory data, find the heat of fusion of water and the percentage error between the standard value and this experimental value.

29. A 100-g iron ball is heated to 100 °C and then placed in a hole in a cake of ice at 0.00 °C. How much ice will melt?



30. How much steam at 100 °C must be mixed with 300 g of water at 20.0 °C to obtain a final water temperature of 80.0 °C?

31. How much steam at 100 °C must be mixed with 1 kg of ice at 0.00 °C to produce water at 20.0 °C?

32. In the laboratory, 6.00 g of steam at 100 °C is placed into an 85.0-g copper calorimeter cup that contains 155 g of water at an initial temperature of 18.5 °C. After the steam condenses, the final temperature of the water is found to be 41.0 °C. From this laboratory data, find the heat of vaporization of water and the percentage error between the standard value and this experimental value.

†33. An electric stove is rated at 1 kW of power. If a pan containing 1.00 kg of water at 20.0 °C is placed on this stove, how long will it take to boil away all the water?

34. An electric immersion heater is rated at 0.200 kW of power. How long will it take to boil 100 cm^3 of water at an initial temperature of 20.0 °C?

Additional Problems

35. Using the specific heat of copper in British engineering units determine how many Btu's are required to raise the temperature of 30 lb of copper from 70.0 °F to 300 °F?

36. A 890-N man consumes 3000 kcal of food per day. If this same energy were used to heat the same weight of water, by how much would the temperature of the water change?

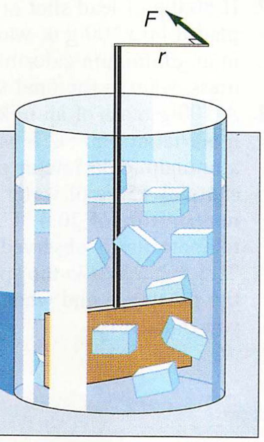
37. An electric space heater is rated at 1.50 kW of power. How many kcal of thermal energy does it produce per second? How many Btu's of thermal energy per hour does it produce?

†38. A 0.055-kg mass of lead at an initial temperature of 135 °C, a 0.075-kg mass of brass at an initial temperature of 185 °C, and a 0.0445-kg of ice at an initial temperature of −5.25 °C is placed into a calorimeter containing 0.250 kg of water at an initial temperature of 23.0 °C. The aluminum calorimeter has a mass of 0.085 kg. Find the final temperature of the mixture.

39. A 100-g lead bullet is fired into a fixed block of wood at a speed of 350 m/s. If the bullet comes to rest in the block, what is the maximum change in temperature of the bullet?

†40. A 35-g lead bullet is fired into a 6.5-kg block of a ballistic pendulum that is initially at rest. The combined bullet-pendulum rises to a height of 0.125 m. Find (a) the speed of the combined bullet-pendulum after the collision, (b) the original speed of the bullet, (c) the original kinetic energy of the bullet, (d) the kinetic energy of the combined bullet-pendulum after the collision, and (e) how much of the initial mechanical energy was converted to thermal energy in the collision. If 50% of the energy lost shows up as thermal energy in the bullet, what is the change in energy of the bullet?

†41. After 50.0 g of ice at 0 °C is mixed with 200 g of water, also at 0 °C, in an insulated cup of 15.0-cm radius, a paddle wheel, 15.0 cm in radius, is placed inside the cup and set into rotational motion. What force, applied at the end of the paddle wheel, is necessary to rotate the paddle wheel at 60 rpm, for 10.0 minutes such that the final temperature of the mixture will be 15.0 °C?



†42. A 75.0-kg patient is running a fever of 105 °F and is given an alcohol rub down to lower the body temperature. If the specific heat of the human body is approximately 0.830 kcal/(kg °C), and the heat of vaporization of alcohol is 203 kcal/kg, find (a) the amount of heat that must be removed to lower the temperature to 102 °F and (b) the volume of alcohol required.

43. How much thermal energy is required to heat the air in a house from 15.0 °C to 20.0 °C if the house is 14.0 m long, 9.00 m wide, and 3.00 m high?

44. A classroom is at an initial temperature of 20 °C. If 35 students enter the class and each liberates heat to the air at the rate of 100 W, find the final temperature of the air in the room 50 min later, assuming all the heat from the students goes into heating the air. The classroom is 10.0 m long, 9.00 m wide, and 4.00 m high.

45. How much fuel oil is needed to heat a 100-gal tank of water from 40.0 °F to 180 °F, if oil is capable of supplying 140,000 Btu of thermal energy per gallon of oil?

46. How much fuel oil is needed to heat a 570-liter tank of water from 10.0 °C to 80.0 °C if oil is capable of supplying 3.88×10^7 J of thermal energy per liter of oil?

47. How much heat is necessary to melt 100 kg of aluminum initially at a temperature of 20 °C? The melting point of aluminum is 660 °C and its heat of fusion is 90 kcal/kg.

†48. If the heat of combustion of natural gas is 1000 Btu/ft^3, how many ft^3 are needed to heat 26 ft^3 of water from 60.0 °F to 180 °F in a hot water heater if the system is 75% efficient?

49. If the heat of combustion of natural gas is 3.71×10^7 J/m^3, how many cubic meters are needed to heat 0.580 m^3 of water from 10.0 °C to 75.0 °C in a hot water heater if the system is 63% efficient?

†50. If the heat of combustion of coal is 12,000 Btu/lb, how many pounds of coal are necessary to heat 26 ft^3 of water from 60 °F to 180 °F in a hot water heater if the system is 75% efficient?

51. If the heat of combustion of coal is 2.78×10^7 J/kg, how many kilograms of coal are necessary to heat 0.580 m^3 of water from 10.0 °C to 75.0 °C in a hot water heater if the system is 63% efficient?

†52. The *solar constant* is the amount of energy from the sun falling on the earth per second, per unit area and is given as SC = 1350 J/(s m^2). If an average roof of a house is 60.0 m^2, how much energy impinges on the house in an 8-hr period? Express the answer in joules, kWhr, Btu, and kcal. Assuming you could convert all of this heat at 100% efficiency, how much fuel could you save if #2 fuel oil supplies 140,000 Btu/gal; natural gas supplies 1000 Btu/ft^3; electricity supplies 3415 Btu/kWhr?

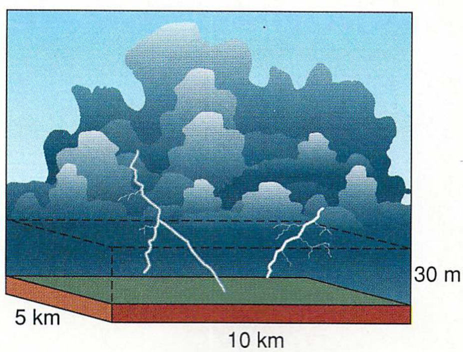
53. How much thermal energy can you store in a 2000-gal tank of water if the water has been subjected to a temperature change of 70.0 °F in a solar collector?

54. How much thermal energy can you store in a 5680-liter tank of water if the water has been subjected to a temperature change of 35.0 °C in a solar collector?

55. The refrigerating capacity of some older air conditioners were rated in terms of tons. A 1-ton air conditioner extracted enough thermal energy to freeze 1 ton of water at 32 °F per day. How much thermal energy is necessary to freeze 1 ton of water? If it takes 24 hr to freeze this water, how much power is expended in Btu/hr and watts? Compare this value to the rating of modern air conditioners.

56. A 5.94-kg lead ball rolls without slipping down a rough inclined plane 1.32 m long that makes an angle of 40.0° with the horizontal. The ball has an initial velocity v_0 = 0.25 m/s. The ball is not perfectly spherical and some energy is lost due to friction as it rolls down the plane. The ball arrives at the bottom of the plane with a velocity v = 3.00 m/s, and 80.0% of the energy lost shows up as a rise in the temperature of the ball. Find (a) the height of the incline, (b) the initial potential energy of the ball, (c) the initial kinetic energy of translation, (d) the initial kinetic energy of rotation, (e) the initial total energy of the ball, (f) the final kinetic energy of translation, (g) the final kinetic energy of rotation, (h) the final total mechanical energy of the ball at the bottom of the plane, (i) the energy lost by the ball due to friction, and (j) the increase in the temperature of the ball.

†57. The energy that fuels thunderstorms and hurricanes comes from the heat of condensation released when saturated water vapor condenses to form the droplets of water that become the clouds that we see in the sky. Consider the amount of air contained in an imaginary box 5.00 km long, 10.0 km wide, and 30.0 m high that covers the ground at the surface of the earth at a particular time. The air temperature is 20 °C and is saturated with all the water vapor it can contain at that temperature, which is 17.3 × 10^{-3} kg of water vapor per m^3. The air in this imaginary box is now lifted into the atmosphere where it is cooled to 0 °C. Since the air is saturated, condensation occurs throughout the cooling process. The maximum water vapor the air can contain at 0 °C is 4.847 × 10^{-3} kg of water vapor per m^3. (The heat of vaporization of water varies with temperatures from 600 kcal/kg at 0 °C to 540 kcal/kg at 100 °C. We will assume an average temperature of 10.0 °C for the cooling process.) Find (a) the volume of saturated air in the imaginary box, (b) the mass of water vapor in this volume at 20.0 °C, (c) the mass of water vapor in this volume at 0 °C, (d) the heat of vaporization of water at 10.0 °C, and (e) the thermal energy given off in the condensation process. (f) Discuss this quantity of energy in terms of the energy that powers thunderstorms and hurricanes.



Interactive Tutorials

58. Find the total amount of thermal energy in joules necessary to convert ice of mass m_i = 2.00 kg at an initial temperature t_{ii} = −20.0 °C to water at a final water temperature of t_{fw} = 88.3 °C. The specific heat of ice is c_i = 2093 J/kg °C, water is c_w = 4186 J/kg °C, and the latent heat of fusion of water is L_f = 3.34 × 10^5 J/kg.

59. If a sample of lead shot of mass m_s = 0.080 kg and initial temperature t_{is} = 100 °C is placed into a mass of water m_w = 0.100 kg in an aluminum calorimeter of mass m_c = 0.060 kg at an initial temperature t_{iw} = 20.0 °C, what is the final equilibrium temperature of the water, calorimeter, and lead shot? The specific heats are water c_w = 4186 J/kg °C, calorimeter c_c = 900 J/kg °C, and lead sample c_s = 129.8 J/kg °C.

60. Temperature Conversion Calculator. The Temperature Conversion Calculator will permit you to convert temperatures in one unit to a temperature in another unit.

61. Specific heat. A specimen of lead, m_s = 0.250 kg, is placed into an oven where it acquires an initial temperature t_{is} = 200 °C. It is then removed and placed into a calorimeter of mass m_c = 0.060 kg and specific heat c_c = 900 J/kg °C that contains water, m_w = 0.200 kg, at an initial temperature t_{iw} = 10.0 °C. The specific heat of water is c_w = 4186 J/kg °C. The final equilibrium temperature of the water in the calorimeter is observed to be t_{fw} = 16.7 °C. Find the specific heat c_s of this sample.

62. Find the total amount of thermal energy in joules necessary to convert ice of mass m_i = 12.5 kg at an initial temperature t_{ii} = −25.0 °C to superheated steam at a temperature t_{ss} = 125 °C. The specific heat of ice is c_i = 2093 J/kg °C, water is c_w = 4186 J/kg °C, and steam is c_s = 2013 J/kg °C. The latent heat of fusion of water is L_f = 3.34 × 10^5 J/kg, and the latent heat of vaporization is L_v = 2.26 × 10^6 J/kg.

63. A mixture. How much ice at an initial temperature of t_{ii} = −15.0 °C must be added to a mixture of three specimens contained in a calorimeter in order to make the final equilibrium temperature of the water t_{fw} = 12.5 °C? The three specimens and their characteristics are sample 1: zinc; m_{s1} = 0.350 kg, c_{s1} = 389 J/kg °C, initial temperature t_{is1} = 150 °C; sample 2: copper; m_{s2} = 0.180 kg, c_{s2} = 385 J/kg °C, initial temperature t_{is2} = 100 °C; and sample 3: tin; m_{s3} = 0.350 kg, c_{s3} = 226 J/kg °C, initial temperature t_{is3} = 180 °C. The calorimeter has a mass m_c = 0.060 kg and specific heat c_c = 900 J/kg °C and contains water, m_w = 0.200 kg, at an initial temperature t_{iw} = 19.5 °C. The specific heat of water is c_w = 4186 J/kg °C.