CHAPTER 18
Temperature, Heat & The First Law of Thermodynamics

- Equilibrium & temperature scales
- Thermal expansion
- Exchange of heat
- First law of thermodynamics
- Heat conduction

\[ \text{\Delta 1.} \text{ The volume of 1.00 kg water is 958.38 mm}^3 \text{ at a temperature of 10.0 °C and 999.73 mm}^3 \text{ at a temperature of 100.0 °C. Calculate the coefficient of volume expansion for water in that range of temperature. (Ans: } 4.79 \times 10^{-4} \text{ °C}^{-1} \text{)} \]

\[ \text{\Delta 2.} \text{ An isolated rod is in thermal contact with a hot reservoir at one end and with a cold reservoir at other end (figure 1). The rod consists of a 1.00-m section of copper joined by a section of length } L_2 \text{ of steel. Both rods have the same cross sectional area of } 4.00 \text{ cm}^2 \text{. The temperature of the copper-steel junction } T_j \text{ is 65 °C. Assume steady state, find } L_2 \text{. [ } k_{\text{steel}} = 14 \text{ W/m.K}; k_{\text{cu}} = 401 \text{ W/m.K} \text{] (Ans: 0.065 m)} \]

\[ \text{\Delta 3.} \text{ How much ice at -20.0 °C must be mixed with 0.25 kg of water, initially at 20.0 °C, to obtain a final temperature of mixture of 0.0°C with all ice melted? [ } c_{\text{ice}} = 2220 \text{ J/kg K} \text{] (Ans: 56 g)} \]

\[ \text{\Delta 4.} \text{ A square hole 8.00 cm along each side is cut in a sheet of metal. If the temperature of the sheet is increased by 50 K, the area of the hole increases by 0.11 cm}^2 \text{. Find the coefficient of linear expansion } \alpha \text{ of the metal. (Ans: } 17.2 \times 10^{-6} \text{ °C}^{-1} \text{)} \]

\[ \text{\Delta 5.} \text{ Helium condenses into the liquid phase at approximately 4 K. What is the corresponding temperature in degrees Fahrenheit? (Ans: -452)} \]

\[ \text{\Delta 6.} \text{ A gas is compressed from 600 cm}^3 \text{ to 200 cm}^3 \text{ at a constant pressure of 400 kPa. At the same time, 100 J of heat is transferred out of gas. What is change in the internal energy of the gas during this process? (Ans: 60 J)} \]

\[ \text{\Delta 7.} \text{ A 15-g ice cube at 0 °C is placed in an aluminum cup whose initial temperature is 70 °C. The system comes to an equilibrium temperature of 20 °C. What is the mass of the cup? [ } c_{\text{Al}} = 900 \text{ J/kg.K}; L_{\text{f,ice}} = 333 \text{ kJ/kg.K} \text{] (Ans: 140 g)} \]

\[ \text{\Delta 8.} \text{ Two cylindrical copper rods, with different lengths } L_1 \text{ and } L_2 \text{ and different diameters } D_1 \text{ and } D_2 \text{, are connected across two heat reservoirs with temperatures } T_L = 0 °C \text{ and } T_H = 100 °C \text{, as shown in figure 2. In steady state, the heat conduction rate through the rod } L_1 \text{ is half of that through } L_2 \text{. If } L_1 = 40 \text{ cm}, D_2 = 1.2 D_1 \text{, what is the length } L_2 \text{? [ } k_{\text{copper}} = 385 \text{ W/m.K} \text{] (Ans: 29 cm)} \]

\[ \text{\Delta 9.} \text{ A glass flask with volume 250 cm}^3 \text{ is filled with mercury at 25 °C. How much mercury overflows when the temperature of the system is raised to 105 °C? [ } \alpha_{\text{glass}} = 4.0 \times 10^{-6} \text{ K}^{-1} \text{ and } \beta_{\text{mercury}} = 1.82 \times 10^{-4} \text{ K}^{-1} \text{] (Ans: 3.4 cm}^3 \text{)} \]

\[ \text{\Delta 10.} \text{ A metal rod has a length of 7.30 m at 15 °C and a length of 7.40 m at 95 °C. What is the temperature of the rod when its length is 7.21 m? (Note: take } T_i = 15 °C \text{) (Ans: -57 °C)} \]
11. 100 g of ice at 0 °C is mixed with 100 g of water at 70 °C, what is the final temperature of the mixture? (Ans: 0 °C)

12. Figure 3 shows five slabs of different materials with equal thickness and same cross sectional area, placed side by side. Heat flows from left to right and steady state temperatures are given at the interfaces. Which slab has largest thermal conductivity? (Ans: 3)

13. A steel rod is 4.000 cm in diameter at 35 °C. A brass ring has an inner diameter of 3.992 cm at 35 °C. At what common temperature will the brass ring slide onto steel rod? [\(a_{\text{steel}} = 11 \times 10^{-6} \text{ /K}^{-1}, a_{\text{brass}} = 19 \times 10^{-6} \text{ /K}^{-1}\)] (Ans: 286 °C)

14. What mass of steam initially at 100 °C should be mixed with 160 g of ice at 0 °C in a thermally insulated container to produce liquid water at 40 °C? (Ans: 32 g)

15. A 20-kg block of copper is dropped and falls 122 m. Calculate the rise in the temperature of the block if all the potential energy lost in the fall is converted to heat. [specific heat of copper = 386 J/kg.K] (Ans: 3.1 K)

16. Figure 4 shows a steel bar 15 cm long welded end to end to a copper bar 30 cm long. Each bar has a square cross sectional area of 2.2 cm². The free end of steel is maintained at 100 °C and the free end of copper is maintained at 0 °C. Find the temperature at the junction of the two bars, assuming steady state.

\[k_{\text{steel}} = 50.2 \text{ W/m.K, } k_{\text{copper}} = 385 \text{ W/m.K}\] (Ans: 21 °C)

17. A 2.0-cm diameter cylinder contains 50 mL of water at 10.0 °C. What is the change in the water level when the temperature rises to 80 °C? Ignore the change in the volume of the tube. [\(\beta_{\text{water}} = 2.1 \times 10^{-4} \text{/°C}, \) and \(1 \text{ mL} = 1 \text{ cm}^3\)] (Ans: 0.23 cm)

18. 500 g of steam at 100 °C lose 1.180×10⁶ J of heat. Calculate the final temperature? [Heat of vaporization of water is 2.256 ×10⁶ J/kg, heat of fusion is 333 kJ/kg, and the specific heat of water = 4.19 kJ/kg K] (Ans: 75 °C)

19. The temperature of one side of an 8.0-mm thick glass window is maintained at 45 °C while the other side is maintained at 25 °C. If the area of the window is 2.0 m², how much energy is transferred through the window in 5 hours? [\(k_{\text{glass}} = 1.0 \text{ W/m.K}\)] (Ans: 90 ×10⁶ J)

20. Figure 5 shows an aluminum and an iron rods joint together. The rods have the same cross section and their sides are insulated. In steady state, find the temperature \(T_J\) at the far end of the iron rod. [\(k_{\text{Al}} = 235 \text{ W/mK}\) and \(k_{\text{iron}} = 14 \text{ W/mK}\)] (Ans: 302 °C)

21. An iron ball has a diameter of 6.00 cm and is 0.01 cm larger than the diameter of a brass ring. Both are at a temperature of 20 °C. To what temperature should the brass ring be heated so that the ball just passes through the hole? [\(a_{\text{brass}} = 1.9 \times 10^{-5} \text{ K}^{-1}\)] (Ans: 108 °C)

22. A person wants to cool 0.3 kg of water that is initially at 30 °C by adding ice initially at -25 °C. How much ice should he add so that the final temperature will be 0 °C, with all the ice melted? [For ice, use the specific heat = 2.1×10³ J/ (kg.K), and heat of fusion = 3.3×10⁵ J/kg] (Ans: 99 g)

23. In a p-V diagram, a system of an ideal gas goes through the process shown in figure 6. How much heat is absorbed after the system goes through this cycle 10 times. [Take \(P = 1.0 \text{ Pa}\) and \(V = 1.0 \text{ m}^3\)] (Ans: 20 J)

24. It is recommended to use a new temperature scale called Z. On the Z scale, the boiling point of water is 65.0 °Z and the freezing point is -15.0 °Z. To what temperature on the Fahrenheit scale would a temperature of -100 °Z correspond? [Note: both scales are linear] (Ans: -159 °F)
25. Fifty grams of ice at 0 °C is placed in a thermos bottle containing 100 grams of water at 6.0 °C. How many grams of ice will melt? (Ans: 7.5 g)

26. A cylinder with a frictionless piston contains 0.2 kg of water at 100 °C. What is the change in the internal energy of water when it is converted to steam at 100 °C at a constant pressure of 1 atm. \( \rho_{\text{steam}} = 0.6 \text{ kg/m}^3 \) and \( \rho_{\text{water}} = 10^3 \text{ kg/m}^3 \) (Ans: 418 kJ)

27. Consider a copper slab of thickness \( L \) and area of 5.0 m\(^2\). If the conduction rate through the copper slab is \( 1.2 \times 10^6 \text{ J/s} \) and the temperature on the left of the slab is 102 °C while on the right of the slab it is -12.0 °C, what must be the thickness of the slab? \( k_{\text{copper}} = 400 \text{ W/(m.K)} \) (Ans: 19 cm)

28. Calculate the amount of energy required to completely melt 130 g of lead initially at temperature of 15.0 °C. [Melting point of lead = 328 °C, latent heat of fusion of lead = 2.32 \times 10^4 \text{ J/kg}, and the specific heat of lead = 128 J/kg.K] (Ans: 8.22 \times 10^3 J)

29. When the temperature of a metal sphere is raised by 75 °C, the sphere’s volume increases by 6.9 \times 10^{-5} \text{ m}^3. If the original volume is 1.8 \times 10^{-2} \text{ m}^3, find the coefficient of linear expansion of the sphere. (Ans: 1.7 \times 10^{-5} \text{ oC})

30. Liquid nitrogen boils at a temperature of -196 °C when the pressure is one atmosphere. A silver coin of mass 15 g and temperature 25 °C is dropped into the liquid. What mass of nitrogen boils off as the coin cools to – 196 °C? [Take the specific heat of silver = 235 J/Kg/K, and latent heat of vaporization for liquid nitrogen is 2.0 \times 10^5 J/Kg] (Ans: 3.9 g)

31. How much heat is required to melt ice of mass 500 g at -10 °C to water at 0 °C? [specific heat of ice: \( c = 2220 \text{ J/(kg.K)} \); heat of fusion of ice: \( L_f = 333 \times 10^3 \text{ J/kg} \)] (Ans: 1.78 \times 10^5 J)

32. A steel washer (ring) has an inner diameter of 4.000 cm and an outer diameter of 4.500 cm at 20 °C. To what temperature must the washer be heated to just fit over a rod that is 4.010 cm in diameter? \( \alpha_{\text{steel}} = 11 \times 10^{-6}/\text{ oC} \) (Ans: 247 °C)

33. A cylindrical copper rod of length 1.5 m and cross sectional area 6.5 cm\(^2\) is insulated to prevent heat loss through its surface. The ends are maintained at a temperature difference of 100 °C by having one end in a water-ice mixture and the other in boiling water and steam. How much ice is melted per hour at the cold end? [thermal conductivity of copper = 401 W/(m.K); heat of fusion of ice \( L_f = 333 \times 10^3 \text{ J/kg} \)] (Ans: 188 g)

34. The coefficient of linear expansion of gold is 14.20 \times 10^{-6}/\text{K}. If the density of gold is 19.30 g/cm\(^3\) at 20 °C, what will be the density of gold at 90 °C? (Ans: 19.24 g/cm\(^3\))

35. A thermometer, of mass 0.06 kg and specific heat 836 J/kg.K, reads 15 °C. It is then completely immersed in 0.15 kg of water of specific heat 4180 J/kg.K. The final temperature reading of the thermometer in the water is 45 °C. Assuming no heat losses from the system to the surrounding, what was the initial temperature of the water? (Ans: 47.4 °C)

36. At what reading do the Fahrenheit and Kelvin scales agree? (Ans: 574)

37. A lead bullet, traveling at 200 m/s, strikes a tree and comes to rest. If half the heat produced is retained by the bullet. What will be the change in the temperature of the bullet? Assume that all the kinetic energy is converted to heat energy. [specific heat of lead = 0.125 \times 10^3 J/kg.°C] (Ans: 80 C°)

38. Consider a steel plate with area 2.0 m\(^2\) at 20 °C. What is the magnitude of the change in its area when the temperature is lowered to -20 °C? [coefficient of linear expansion of steel = 11.7 \times 10^{-6}/\text{ oC}] (Ans: 1.9 \times 10^{-3} m\(^2\))
39. Copper pellets, each of mass 1.0 g, are heated to 100 °C. How many pellets must be added to 500 g of water initially at 20 °C to make the final equilibrium temperature 30 °C? [Neglect the heat capacity of the container, specific heat of copper = 0.0924 cal/g.°C, and specific heat of water = 1.0 cal/g.°C] (Ans: 773)

40. A gas expands from a volume of 2.00 m³ to a volume of 6.00 m³ along two different paths, as shown in figure 7. The heat added to the gas along path IAF equals 1.68 × 10⁶ J. Find the heat added during path IF. (Ans: 1.48 × 10⁶ J)

41. Two containers A and B, each having 1.0 kg of water, are initially at 20 °C. Container A is heated by 10 K, while container B is heated by 10 °F. Then, they are mixed. What is the final temperature? (Ans: 27.8 °C)

42. In the p-V diagram shown in figure 8, 150 J of heat is added to the system in process AB, and 600 J of heat is added to the system in process BD. What is the total heat added in process ACD? (Ans: 600 J)

43. Two steel rods are each 1.000 m long at 20.0 °C. Their ends are 1.00 mm apart, as shown in figure 9. To what common temperature should they be heated so that their ends touch at point A? [αsteel = 11×10⁻⁶/°C] (Ans: 111 °C)

44. Heat flows through a slab. It takes 1.0 minute to transfer 600 J of thermal energy across the slab. If the slab thickness is doubled, its cross-sectional area is halved, and the temperature difference across it is doubled, how long will it take to transfer the same amount of thermal energy? (Ans: 120 s)

45. A gas within a closed chamber is taken through the cycle shown in the p-V diagram of figure 10. Calculate the net energy added as heat, and the change in the internal energy of the gas per cycle. (Ans: Q = -120 J, ΔEint = 0)

46. A closed cubical box (60 cm on edge and 5 cm on thickness) contains ice at 0 °C. When the outside temperature is 20 °C, it is found that 250 grams of ice melt each hour. What is the thermal conductivity of the walls of the box? (Ans: 0.027 W/m.K)

47. How much water remains unfrozen after 50.2 kJ is transferred as heat from 260 g of liquid water initially at 0 °C? (Ans: 109 g)

48. A room has a window made of two layers of glass separated by an air layer as in figure 11. Each of the 3 layers has a thickness of 0.50 mm and an area of 1.0 m². The temperature outside the room is -20 °C, while the temperature inside the room is +20 °C. What is the rate of heat transfer by conduction through the window? Assume steady state. [kglass = 1.0 W/m.K, kair = 0.026 W/m.K] (Ans: 2.0 kW)

49. The heat lost by 300 g of a metal as it cools by 50.0 °C raises the temperature of 300 g of water by 10.0 °C. The specific heat of water is 4190 J/kg.K. What is the specific heat of the metal? (Ans: 838 J/kg.K)

50. A block of 200 g of copper is dropped into a container that has 500 g of water. Both are at a temperature T = 90 °C. The system is left to cool down slowly. What is the temperature of the system when the heat lost by the water and the copper is 2.0×10⁴ J? Neglect any heat gained or lost by the container. The specific heats of water and copper are 4180 J/kg K and 386 J/kg.K, respectively. (Ans: 81 °C)

51. A 2.00-kg sample of steam at 100 °C loses 2.26 kJ of heat. What is the final temperature of the sample? (Ans: 100 °C)

52. Heat is conducted by two cylindrical rods, connected in series, with identical cross sectional area and length, as shown in figure 12. One of the rods is made of carbon; the other is made of silver. Find the ratio of the conduction rate of the silver rod to the conduction rate of the carbon rod in a steady state condition. [ksilver = 440W/m.K, κcarbon = 1100 W/m.K] (Ans: 1.00)
53. Heat is conducted by two cylindrical rods with identical cross sectional area and length (see figure 13). The temperature difference between the ends of each rod is the same. One of the rods is made of carbon, while the other is made of silver. What is the ratio of the conduction rate of the silver rod to the conduction rate of the carbon rod? \( \kappa_{\text{silver}} = 440 \text{W/m.K}, \kappa_{\text{carbon}} = 1100 \text{W/m.K} \) (Ans: 0.40)

54. Find the change in volume of an aluminum sphere, with an initial radius of 0.1 m, when it is heated from 0.0 °C to 100 °C. \( \alpha_{\text{Al}} = 23 \times 10^{-6}/\text{°C} \) (Ans: 29 cm³)

55. A bridge is made from segments of concrete that are 50 m long each. If the linear expansion coefficient of concrete is 12.0 \times 10^{-6}/°C, how much spacing is needed to allow for expansion for an extreme change in temperature of 150 °F? (Ans: 5.0 cm)

56. Two metal rods, one silver and the other copper, each is 5.00 cm long and has a square cross-section 2.00 cm on a side. As shown in figure 14, both rods are connected in parallel between a steam chamber at a temperature of 100 °C, at one end, and an ice-water bath, with a temperature of 0 °C, at the other. How much heat flows through the two rods in 1.00 minute? \( \kappa_{\text{silver}} = 417, \kappa_{\text{copper}} = 395 \text{W/(m·K)} \) (Ans: 39.0 kJ)

57. A steel ball has a radius of 10 cm at 20 °C. What is the magnitude of the change in its volume when the temperature is lowered to −20 °C? \( \alpha_{\text{steel}} = 11.7 \times 10^{-6}/\text{°C} \). (Ans: 5.9×10^{-6} m³)

58. One end of a cylindrical rod of length 50.0 cm and cross sectional area 11.5 cm² is placed in a steam bath at 100 °C whereas the other end is inserted into an ice bath at 0 °C. If 500 g of ice melts in 30.0 min, what is the rod made up of? (Ans: Copper: \( k = 402 \text{W/m.K} \))

59. 1.00 kg of steam at 100 °C is mixed with 1.00 kg of ice at 0 °C. Assuming the system is isolated, what is the final temperature of the mixture? (Ans: 100 °C)

60. When the average temperature of the earth increases by 1.00 °C, commonly known as global warming, by what percentage will the volume of the ocean due to expansion be increased? \( \beta = 2.07 \times 10^{-4}/\text{°C} \) (Ans: 0.02%)

61. Five grams of ice at 0 °C is placed in an insulated container having 100 grams of water at 100 °C. What is the final temperature of the mixture? (Ans: 91.4 °C)

62. At 20 °C, a brass cube has an edge length of 10 cm. What is the increase in the cube’s total surface area when it is heated from 20°C to 75°C? \( \alpha_{\text{brass}} = 19 \times 10^{-6}/\text{K} \) (Ans: 1.3 cm²)

63. The melting point of sulfur is 444.6 °C, and is 586.1 °F below its boiling point. Determine the boiling point of sulfur in degrees Celsius. (Ans: 770.2 °C)

64. A metallic rod has a length of 60 cm. One end is maintained at 80 °C and the other end is at 20 °C. In steady state, what is the temperature of the rod at a point which is 20 cm from the hot end? (Ans: 60 °C)

65. A 200-g ice cube at 0.0 °C is dropped into 350 g of water at 20 °C. What is the temperature of the mixture when it reaches thermal equilibrium? (Ans: 0.0 °C)

66. A steel rod is placed between two parallel walls, as shown in figure 16. At 20 °C, the rod has a length of 3.5 m and is separated by 1.0 mm from each wall. The rod is heated uniformly. At what temperature will it touch both walls? The coefficient of linear expansion of steel is \( 11 \times 10^{-6}/\text{°C}^{-1} \). (Ans: 72 °C)

67. The specific heat of object B is twice that of object A, and the mass of object A is three times the mass of object B. Initially A is at 300 K, and B is at 450 K. They are placed in thermal contact with each other and the combination is isolated. What is the final temperature of both objects? (Ans: 360 K)
68. The change in the internal energy of an ideal gas as it moves from \( a \) to \( c \) along the path \( abc \) is -300 J (see figure 18). As it moves from \( c \) to \( d \), 280 J is transferred to it as heat. As the gas moves from \( d \) to \( a \), it absorbs 110 J as heat. How much work is done by the gas as it moves from \( c \) to \( d \)? (Ans: +90 J)

69. A cubic tank filled with 5.0 kg of water is insulated from all sides except its top which is covered with a square glass sheet of length 2.0 m and thickness 3.0 cm. The water is initially at 20 °C. It is exposed for 20 seconds to the outside environment where the temperature is 55 °C. Find the change in the temperature of water (assume that heat is distributed uniformly in the water). \( (k_{\text{glass}} = 1.0 \text{ W/m.K}) \) (Ans: 4.5 °C)

Conceptual Problems

1. A bar of copper is heated from 280 K to 300 K. Which of the following statements is not true?
   A. Its density will increase slightly.
   B. Its length will increase slightly.
   C. Its electrical resistance will increase slightly.
   D. Its mass will remain unchanged.
   E. Its weight will remain unchanged.

2. Which one of the following statements is wrong?
   A. Two bodies can be in thermal contact for a very long time without being in thermal equilibrium.
   B. The density of most substances decreases when they are heated.
   C. If two bodies are in thermal equilibrium then they must have the same temperature.
   D. Generally, liquids expand more than solids for the same temperature change.
   E. Most solid materials contract when cooled.

3. In a thermodynamic process, the internal energy of a system in a container with adiabatic walls decreases by 800 J. Which of the following statements is correct?
   A. The system performed 800 J of work on its surroundings.
   B. The system gained 800 J by heat transfer from its surroundings.
   C. The system lost 800 J by heat transfer to its surroundings.
   D. The surrounding performed 800 J of work on the system.
   E. The 800 J of work done by the system was equal to the 800 J of heat transferred to the system from its surroundings.

4. Specify the wrong statement.
   A. Two bodies are in thermal equilibrium with each other if their temperatures are different.
   B. A thermometer is an instrument that measures temperature.
   C. Two bodies in thermal equilibrium with a third, are in thermal equilibrium with each other.
   D. If two bodies are in thermal contact, they can have initially different temperatures.
   E. Celsius, Fahrenheit and Kelvin are three temperature scales.
5. Body A is at higher temperature than Body B. When they are placed in contact, heat will flow from A to B
   A. until both have the same temperature.
   B. only if the specific heat of A is larger than that of B.
   C. only if the volume of A is larger than that of B.
   D. only if A has the greater internal energy content.
   E. only if the thermal conductivity of A is greater than that of B.

6. Two different materials have the same mass and are at the same initial temperature. Equal quantities of energy are absorbed as heat by each. Their final temperature may be different because they have different:
   A. specific heat.
   B. coefficients of expansion.
   C. densities.
   D. thermal conductivities.
   E. volumes.

7. Which of the following statements is true?
   A. If two objects are in thermal equilibrium they must have the same temperature.
   B. 272 K is warmer than 0 °C.
   C. If an object (A) is warmer than a second object (B) in the Fahrenheit scale, then object (B) must be warmer than object (A) in the Celsius scale.
   D. When the temperature of an object increases by one °C, it means that it has increased by less than one °F.
   E. The coefficient of linear expansion is the same for all materials.

8. Which of the following statements is wrong?
   A. If work is done on a system, the internal energy of the system decreases in an adiabatic process.
   B. In an adiabatic process, transfer of energy as heat is zero.
   C. In a constant-volume process, the internal energy of the system increases if heat is added.
   D. In a cyclic process, the change in internal energy of the system is zero.
   E. Heat energy can be transferred only between bodies having different temperatures.

9. Which one of the following statements is correct?
   A. Temperatures which differ by 10° on the Celsius scale must differ by 18° on the Fahrenheit scale.
   B. Temperatures differing by 25° on the Fahrenheit scale must differ by 45° on the Celsius scale.
   C. 40 K corresponds to – 40 °C.
   D. Water at 96 °C is warmer than water at 212 °F.
   E. 0 °F corresponds to – 32 °C.

10. In a certain process, a gas ends in its original thermodynamic state. Of the following, which is possible as the net result of the process?
    A. The gas absorbs 50 J of energy as heat and does 50 J of work.
    B. It is adiabatic and the gas does 50 J of work.
    C. The gas does no work but absorbs 50 J of energy as heat.
    D. The gas does no work but rejects 50 J of energy as heat.
    E. The gas rejects 50 J of heat and does 50 J of work.
11. On a cold winter day, metallic objects generally feel cooler to the touch than wooden objects. This is because:

A. metals conduct heat better than wood.
B. a given mass of wood contains more heat than the same mass of metal.
C. heat tends to flow from metal to wood.
D. the equilibrium temperature of metal is lower than that of wood.
E. the mass density of wood is less than the mass density of metals.

12. A system undergoes an adiabatic process in which its internal energy increases by 20 J. Which of the following correctly describes changes in the system?

A. Heat: none, Work: 20 J on the system
B. Heat: none, Work: 20 J by the system
C. Heat: 20 J removed, Work: none
D. Heat: 20 J added, Work: none
E. Heat: 40 J added, Work: 20 J by the system

13. In a certain cyclic process a gas ends in its initial thermodynamic state. Which one of the following statements is possible as the net result of the process?

A. The gas absorbs 50 J of heat and does 50 J of work.
B. The gas absorbs 50 J of heat and 50 J of work is done on it.
C. The gas absorbs 100 J of heat and does 50 J of work.
D. The gas rejects 100 J of heat and does 100 J of work.
E. The gas does no work but absorbs 100 J of heat.

14. You take a block of ice at 0 °C and add heat to it at a steady rate. It takes time \( t \) to completely convert the block of ice to steam at 100 °C. What do you have at time \( t/2 \)?

A. A mixture of water and steam at 100 °C.
B. All ice at 0 °C.
C. Water at a temperature between 0 °C and 100 °C.
D. A mixture of ice and water at 0 °C.
E. All steam at 100 °C.

15. A metallic bullet, of mass \( m \) and specific heat \( c \), hits a steel plate with speed \( v \). During the impact, 50% of the bullet’s initial kinetic energy is converted to thermal energy in the bullet. What is the rise in the temperature of the bullet?

A. \( \frac{v^2}{4c} \)
B. \( \frac{v^2}{2c} \)
C. \( \frac{v}{4c} \)
D. \( \frac{v^2}{c} \)
E. \( \frac{v}{2c} \)

16. Which of the following statements are correct?

1. The first law of thermodynamics represents the conservation of energy.
2. Room temperature is about 20 degrees on the Kelvin scale.
3. A calorie is approximately 4.2 J.
4. Heat has the same units as work.
5. Heat is a temperature difference.

A. 1, 3, and 4
B. 2 and 4
C. 1, 2, and 3
D. 3 and 5
E. 1 and 5
17. Which of the following statements is **FALSE** regarding the processes connecting the same points i and f shown in the three diagrams in figure 15?

A. Change in internal energy is different in all three processes
B. Work is different in all three processes
C. Heat energy transfer is different in all three processes
D. The first law of thermodynamics can be applied to the three processes
E. The work is positive in all three processes

18. Which of the following statements are **WRONG**?

1. Two objects are in thermal equilibrium if they have the same temperature.
2. In an isothermal expansion, the work done by the gas is equal to the change in its internal energy.
3. In an adiabatic process, heat lost by the gas is equal to the work done on the gas.
4. In an isochoric process, heat exchanged is equal to the change in internal energy of the gas.

A. 2 and 3  
B. 1 and 2  
C. 1 and 3  
D. 1 and 4  
E. 2 and 4

19. Consider the cyclic process shown in figure 17. If $Q_{BC}$ is negative and $(\Delta E_{in})_{CA}$ is negative, which of the following statement is **CORRECT**?

A. $Q_{AB}$ is positive  
B. $Q_{AB}$ is negative  
C. $Q_{BC}$ is positive  
D. $Q_{CA}$ is positive  
E. $Q_{net} = 0$

20. A sample of a gas undergoes a transition from an initial state $i$ to a final state $f$ by two different paths, $if$ and $ibf$, as shown in figure 19. The energy transferred to the gas as heat along the path $if$ is $10\, p_i \, V_i$. Find the change in internal energy of the gas for the path $ibf$.

A. $6\, p_i \, V_i$  
B. $p_i \, V_i$  
C. $(3/2)\, p_i \, V_i$  
D. $10\, p_i \, V_i$  
E. $(5/2)\, p_i \, V_i$

21. Two rods, made of different materials but having the same length and diameter, are welded end to end between two thermal reservoirs, as shown in figure 20. In steady state, what is the temperature ($T_s$) at the junction between the two rods?

A. $100 \, k_i/ ( k_1 + k_2) $  
B. $100 \, k_i/ ( k_1 + k_2) $  
C. $100 \, k_i \, k_2/ ( k_1 + k_2) $  
D. $50 \, k_i/ ( k_1 + k_2) $  
E. $50 \, k_i/ ( k_1 + k_2) $