son to make a quantitative study of the thermal energy involved in collisions. He crushed a lead ball with a steel cylinder of known mass dropping through a known height and quickly transferred it to a calorimeter. Hirn essentially found that dropping a 423-g mass a distance of 1.0 m produced 1.0 cal. Explain this result and comment on its accuracy.

16. [II] THIS PROBLEM EXPLORES THE TEMPERATURE CHANGE WHEN DIFFERENT QUANTITIES OF WATER ARE MIXING. A sample of water at an initial high Celsius temperature T_{Hi} has a mass m_H. It's to be mixed with a sample of water at an initial low Celsius temperature T_{Li} having a mass m_L. Once combined, a new final Celsius temperature T_f is reached. (a) Write an expression for the heat given up by the high-temperature sample. (b) Write an expression for the heat gained by the low-temperature sample. (c) Taking the heat that flows out of a sample to be negative, and the heat that flows into a sample to be positive, show that

$$T_f = \frac{m_H T_{Hi} + m_L T_{Li}}{m_L + m_H}$$

17. [II] A quantity of cold water at 6.90 °C weighing 20.0 N is mixed with a sample of warm water at 36.9 °C weighing 40.0 N, what will be the final temperature of the mix?

18. [II] A 1000-kg car traveling at 60 km/h is brought to a stop by its braking system. How much thermal energy is evolved in the brakes? Friction with the ground does no work unless there is slipping.

19. [II] Water at 20 °C flows through a 4.0-kW heater at a rate of 1.5 liter/min. Assuming no losses, at what temperature will it emerge? [*Hint: Begin with Eq. (13.1) and divide both sides by time. Watch out for units, especially those of c.*]

20. [II] A refrigeration system removes 10.0 W of thermal energy from the water flowing through it at a rate of 60.0 cm^3/min. By how much will the temperature change each second?

21. [II] A constant stream of water flowing at 1.00 kg/s cools an engine. The water enters the engine at 15.0 °C and leaves at 85.0 °C. How much thermal energy is removed each minute? Give your answer in joules.

22. [II] One gram of carbohydrate burned in a calorimeter liberates 4.10 Cal, and it is estimated that in the body about 98% of that energy finds its way to the cells. If a woman consumes 150 Cal/h jogging, how long must she exercise to burn off 100 g of carbohydrate?

23. [II] Suppose we could convert 1.00 kcal completely into work, thereby raising a 1.00-kg mass in a uniform gravitational field ($g = 9.807\ m/s^2$). How high would it get?

SOLUTION: First we need to determine the energy available in joules. That energy goes into *gravitational*-PE where $PE_G = mgh$. Remembering that 1.00 kcal = 4.186 kJ, this much *gravitational*-PE is equivalent to

$$PE_G = mgh = 4.186\ kJ = (1.00\ kg)(9.807\ m/s^2)h$$

and $$h = (4.186\ kJ)/(9.807\ m/s^2) = 0.427\ km$$

24. [II] A person who has a surface area of 1.65 m^2 consumes energy at about 70 kcal/h while resting. Determine the corresponding metabolic rate (see Discussion Question 3) and compute the approximate amount of thermal energy that will be generated in 2 h.

25. [II] A 50-W immersion heater is placed in a beaker containing 1.0 kg of water at 20 °C. How long will it take to raise the temperature to 100 °C? Neglect any heat losses to the air or beaker.

SECTION 13.4: SPECIFIC HEAT: CALORIMETRY (NO CHANGE IN STATE)

26. [I] How much energy does it take to raise the temperature of 500 g of mercury from −19 °C to 61 °C? Give the answer in both joules and kilocalories.

27. [I] How much thermal energy must be removed from 30 g of tin with a specific heat of 0.060 kcal/kg·K to drop its temperature from 373 K to 283 K? [*Hint: Use the definition of Q and the specific heat of tin.*]

28. [I] How much heat does it take to raise the temperature of 0.40 kg of aluminum from 50 °C to 60 °C given that it has a specific heat of 0.217?

29. [I] If a bar of pure copper is found to absorb 16 kJ in the process of having its temperature raised from 293 K to 353 K, what is the mass of the metal?

30. [I] A 1.00-kg block of ice at −10.0 °C is to be raised to 0.00 °C. How much heat would be necessary? Give your answer in joules.

31. [I] How much energy will be given out upon the complete combustion of 1 gallon of gasoline? One gallon equals 3785 cm^3, and the density is $0.68 \times 10^3\ kg/m^3$.

32. [I] Two beakers of water, one at 15 °C and the other at 95 °C, each contain 1.52 kg of the liquid. If the water is combined, what will its final temperature be, assuming no heat losses from the liquid to the environment?

33. [I] THIS PROBLEM EXPLORES HOW TEMPERATURE CHANGES WITH THE INPUT OF POWER. One way to produce thermal energy in underdeveloped countries that are poor in combustable fuels is to collect sunlight. Suppose a 1.5-m diameter aluminum foil reflector concentrates 510 W of radiant energy onto half a liter of water. (a) Assuming all the energy is imparted to the water, how many joules flow in per second? (b) How much heat is needed to raise the temperature of the water 1.0 °C? (c) How long will it take to raise the temperature of the water 1.0 °C? (d) How long will it take to raise the temperature of the water from 20 °C to 100 °C? Assume any energy losses are negligible.

34. [I] In the winter of 2001 a 13-month-old Canadian girl wandered outside in −20 °C weather wearing only her diaper. When she was found, virtually frozen in the snow, her core body temperature had fallen from its normal value of 37 °C to 15 °C. Despite the fact that the 9-kg toddler had no circulation for some time, she survived without brain damage. How much heat did she lose to the frigid environment? Take the specific heat of the human body to be 3.47 kJ/kg·K.

35. [I] THIS PROBLEM EXPLORES HOW TEMPERATURE CHANGES WITH THE ADDITION OF HEAT. A 1.82-kg copper teapot contains 1.90 kg of water and both are at 20 °C. We want to find out how much heat it will take to raise the temperature of the pot and its contents up to 100 °C. (a) What are the values of the specific heats of both the water and the copper? (b) How much heat (in joules) is need to bring the water to 100 °C? (c) How much heat (in joules) is needed to bring the pot to 100 °C? (d) How many kilocalories must be provided by the stove?

36. [I] THIS PROBLEM EXPLORES THE NOTION OF HEAT CONTENT. For over a thousand years it was common to defend a castle by pouring

hot oil (with a specific heat of ≈2.1 kJ/kg·K and a boiling point of ≈300 °C) down on the heads of the unrelenting invaders. We want to explore the military advantages of oil over water. Assuming the liquid is as hot as possible, and skin temperature is 34 °C, (a) what is the temperature change that would occur for 1.0 kg of each liquid on encountering some unfortunate solder? (b) How much thermal energy would, at most, be transferred per kilogram of each liquid to that poor guy below? (c) So was it worth while to go through all the effort of using oil? Explain. (d) Which property was more important, a high specific heat or a high boiling point?

37. [I] It is found experimentally that by adding 100 g of iron, with a specific heat capacity of 0.113 kcal/kg·K at 80 °C, to a quantity of water at 25 °C, the new equilibrium temperature is 30 °C. What is that amount of water?

38. [I] Suppose we combine 100 g of aluminum with a specific heat capacity of 920 J/kg·K at a temperature of 495 °C with 99.9 g of water at 0.010 °C. What will be the final temperature?

39. [I] A quantity of aluminum shot (c = 910 J/kg·K) at 473 K is mixed with 4.95 kg of water at room temperature, and in a little while, the whole thing comes to equilibrium at 300 K. How much aluminum was used?

40. [I] A 340-g glass mug at 20.0 °C is filled with 250 milliliters of water at 96.0 °C. Assuming no losses to the external environment, what is the final temperature of the mug?

41. [II] According to the *Shooter's Bible*, a 357-magnum bullet has a kinetic energy of 540 ft·lb at 50 yards from the pistol. If it strikes and comes to rest inside a 1.0-kg block of wood (with a specific heat capacity of 1700 J/kg·K), by how much would the block's temperature change? The bullet is lead and weighs 158 grains (1.0 grain is equivalent to 0.064 8 g).

42. [II] In a time of 10.0 s, 20.0 kg of steam enter an engine at 120 °C and leave it at 100°C. What is the rate (in watts) at which energy is transferred to the engine?

43. [II] The 200.5-g copper cup in a calorimeter contains 118.1 g of olive oil with a specific heat of 0.471 kcal/kg·K at room temperature (20.0 °C). An 84.0-g block of glass at 300 °C is dropped into the oil. Determine the final temperature of the cup, oil, and glass. [*Hint: Remember that* $Q_{in} = -Q_{out}$ *and use the definition of* Q.]

44. [II] Suppose we have 0.30 kg of unknown material. It is heated to 371 K and placed into 0.60 kg of room-temperature (20 °C) water. The water is in a copper cup of mass 0.14 kg surrounded by insulating material, and the final equilibrium temperature is 295 K. Compute the specific heat.

45. [II] A 20-g dried sample of food is placed in an aluminum bomb calorimeter and burned completely. The device consists of an aluminum chamber (0.50 kg) containing the sample, a surrounding water bath (2.00 kg), and an aluminum cup (0.60 kg) holding the water. A thermometer in the water shows that the calorimeter changes temperature from 20 °C to 32 °C; how many kilocalories did the food make available? Neglect the mass of the ash.

46. [II] Let's model the human body as being composed of 75% water and 25% protein. Given that the specific heat of protein is 0.4 cal/g·C°, approximate the specific heat capacity of the body in units of kJ/kg·K.

47. [II] Due to the presence in the body of both minerals (in the bone) and fat, its specific heat is closer to 0.83 cal/g·C° than the value computed in Problem 46. Given that a 150-lb human at a temperature of 98.6 °F must be dropped to a hypothermic value of 93 °F, how much heat must be removed?

48. [II] A 1-kg sample of a material is surrounded by insulation material as in Fig. P48. An electric heater is inserted into a hole in the sample, as is a thermometer. Given that 15 W are supplied by the heater for 16.667 min and the thermometer changes temperature by 16.67 K, what is the specific heat of the sample? Ignore any losses.

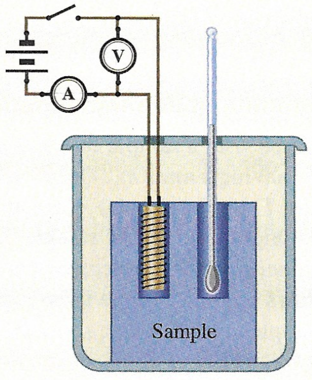

Figure P48

49. [II] The specific heat of a 0.210-kg sample is to be determined. It's first heated to 373 K and then placed into a bath of 0.082 kg of water at 288 K, which is held in a 0.121-kg copper cup at that same temperature. If the final temperature of the system is 310 K, what is the specific heat capacity of the sample?

SOLUTION: When the hot sample(of mass m_x and specific heat c_x) is immersed, the heat-out of it (Q_o) equals the heat-in to the caloimeter (Q_i):

$$Q_o = -c_x m_x \Delta T_x = Q_i = c_w m_w \Delta T_w + c_c m_c \Delta T_c$$
$$-c_x(0.210\ \text{kg})(310\ \text{K} - 373\ \text{K}) = (4.186\ \text{kJ/kg·K})(0.082\ \text{kg})(310\ \text{K} - 288\ \text{K}) + (0.39\ \text{kJ/kg·K})(0.121\ \text{kg})(310\ \text{K} - 288\ \text{K})$$
$$c_x(13.230\ \text{kg·K}) = 7.551\,5\ \text{kJ} + 1.038\,2\ \text{kJ}$$
$$c_x = 0.65\ \text{kJ/kg·K}$$

50. [II] A handful (405 g) of lead shot is removed from boiling water and dropped into a 99.0-g glass beaker containing 198 g of water at 20 °C. If the shot and glass have specific heat capacities of 0.031 kcal/kg·K and 0.20 kcal/kg·K, respectively, find the equilibrium temperature of the system.

51. [II] A 70-kg person engaged in moderate physical activity produces thermal energy internally at a rate of 200 kcal/h. If all the cooling mechanisms become inoperable so there is no dissipation of this energy, how long will it take before the person collapses with a body temperature of 43 °C (109 °F)? (A body temperature of about 44 °C begins to cause irreversible protein damage.) [*Hint: The specific heat of the body is about* 3.5 kJ/kg·K.]

52. [II] How much excess heat is produced when a 65-kg person with the flu experiences a rise in temperature from 98.6 °F to 102 °F? Take the average specific heat of the human body to be 0.83 cal/g·C°.

53. [II] How much hard coal must be burned to raise the temperature of 1.00 kg of water from 0 °C to 100 °C?

54. [III] A house is heated electrically with a system that is 100% efficient; all the power consumed is converted into thermal energy via baseboard heaters. Suppose that it takes 2500 kW·h of energy per month to heat the place. How much wood would be needed to do the same job? Assume the wood stove, which must be exhausted to the outside, is 35% efficient. Given that a cord of wood is a stack of roughly about 1000 kg, how many cords would have to be burned each month?