Chapter 14: Heat and Heat Transfer Methods

# 14.2 Temperature Change and Heat Capacity

|  |  |
| --- | --- |
| 1. | *On a hot day, the temperature of an 80,000-L swimming pool increases by* *. What is the net heat transfer during this heating? Ignore any complications, such as loss of water by evaporation.* |
| Solution | Therefore, |
| 2. | *Show that .* |
| Solution |  |
| 3. | *To sterilize a 50.0-g glass baby bottle, we must raise its temperature from*  *to**. How much heat transfer is required?* |
| Solution |  |
| 4. | *The same heat transfer into identical masses of different substances produces different temperature changes. Calculate the final temperature when 1.00 kcal of heat transfers into 1.00 kg of the following, originally at* *: (a) water; (b) concrete; (c) steel; and (d) mercury.* |
| Solution | (a)  (b)  (c)  (d) |
| 5. | *Rubbing your hands together warms them by converting work into thermal energy. If a woman rubs her hands back and forth for a total of 20 rubs, at a distance of 7.50 cm per rub, and with an average frictional force of 40.0 N, what is the temperature increase? The mass of tissues warmed is only 0.100 kg, mostly in the palms and fingers.* |
| Solution | Let be the number of hand rubs and be the average frictional force of a hand rub: |
| 6. | *A 0.250-kg block of a pure material is heated from  to  by the addition of 4.35 kJ of energy. Calculate its specific heat and identify the substance of which it is most likely composed.* |
| Solution | It is copper. |
| 7. | *Suppose identical amounts of heat transfer into different masses of copper and water, causing identical changes in temperature. What is the ratio of the mass of copper to water?* |
| Solution |  |
| 8. | *(a) The number of kilocalories in food is determined by calorimetry techniques in which the food is burned and the amount of heat transfer is measured. How many kilocalories per gram are there in a 5.00-g peanut if the energy from burning it is transferred to 0.500 kg of water held in a 0.100-kg aluminum cup, causing a*  *temperature increase? (b) Compare your answer to labeling information found on a package of peanuts and comment on whether the values are consistent.* |
| Solution | (a)  (b) A label for unsalted dry roasted peanuts says that 33 g contains 200 calories (kcal), which is  which is consistent with our results to part (a), to one significant figure. |
| 9. | *Following vigorous exercise, the body temperature of an 80.0-kg person is* *. At what rate in watts must the person transfer thermal energy to reduce the body temperature to*  *in 30.0 min, assuming the body continues to produce energy at the rate of 150 W?* |
| Solution | Thus, . |
| 10. | *Even when shut down after a period of normal use, a large commercial nuclear reactor transfers thermal energy at the rate of 150 MW by the radioactive decay of fission products. This heat transfer causes a rapid increase in temperature if the cooling system fails . (a) Calculate the rate of temperature increase in degrees Celsius per second  if the mass of the reactor core is  and it has an average specific heat of . (b) How long would it take to obtain a temperature increase of* *, which could cause some metals holding the radioactive materials to melt? (The initial rate of temperature increase would be greater than that calculated here because the heat transfer is concentrated in a smaller mass. Later, however, the temperature increase would slow down because the  steel containment vessel would also begin to heat up.)* |
| Solution | (a)  Recall that 1 W = 1 J/s. Thus  for 1 s is given by    (b) |

# 14.3 Phase Change and Latent Heat

|  |  |
| --- | --- |
| 11. | *How much heat transfer (in kilocalories) is required to thaw a 0.450-kg package of frozen vegetables originally at*  *if their heat of fusion is the same as that of water?* |
| Solution |  |
| 12. | *A bag containing*  *ice is much more effective in absorbing energy than one containing the same amount of*  *water. (a) How much heat transfer is necessary to raise the temperature of 0.800 kg of water from*  *to* *? (b) How much heat transfer is required to first melt 0.800 kg of*  *ice and then raise its temperature? (c) Explain how your answer supports the contention that the ice is more effective.* |
| Solution | (a)  (b)  (c) The ice is much more effective in absorbing heat because it first must be melted, which requires a lot of energy, then it gains the same amount of heat as the bag that started with water. The first  of heat is used to melt the ice, then it absorbs the  of heat as water. |
| 13. | *(a) How much heat transfer is required to raise the temperature of a 0.750-kg aluminum pot containing 2.50 kg of water from*  *to the boiling point and then boil away 0.750 kg of water? (b) How long does this take if the rate of heat transfer is 500 W []?* |
| Solution | (a)  (b) |
| 14. | *The formation of condensation on a glass of ice water causes the ice to melt faster than it would otherwise. If 8.00 g of condensation forms on a glass containing both water and 200 g of ice, how many grams of the ice will melt as a result? Assume no other heat transfer occurs.* |
| Solution | (Note that  for water at  is used here as a better approximation than  for  water.) |
| 15. | *On a trip, you notice that a 3.50-kg bag of ice lasts an average of one day in your cooler. What is the average power in watts entering the ice if it starts at*  *and completely melts to*  *water in exactly one day []?* |
| Solution |  |
| 16. | *On a certain dry sunny day, a swimming pool’s temperature would rise by*  *if not for evaporation. What fraction of the water must evaporate to carry away precisely enough energy to keep the temperature constant?* |
| Solution | Let be the mass of pool water and  be the mass of pool water that evaporates.    (Note that  for water at  is used here as a better approximation than  for  water.) |
| 17. | *(a) How much heat transfer is necessary to raise the temperature of a 0.200-kg piece of ice from*  *to* *, including the energy needed for phase changes? (b) How much time is required for each stage, assuming a constant 20.0 kJ/s rate of heat transfer? (c) Make a graph of temperature versus time for this process.* |
| Solution | (a) (i) Heat needed to warm ice to  (ii) Heat needed to melt ice at    (iii) Heat required to warm water to    (iv) Heat required to vaporize water at    (v) Heat required to warm vapor to    Total heat required .  (b)  (i)  (ii)  (iii)  (iv)  (v)  Total time  (c) |
| 18. | *In 1986, a gargantuan iceberg broke away from the Ross Ice Shelf in Antarctica. It was approximately a rectangle 160 km long, 40.0 km wide, and 250 m thick. (a) What is the mass of this iceberg, given that the density of ice is ? (b) How much heat transfer (in joules) is needed to melt it? (c) How many years would it take sunlight alone to melt ice this thick, if the ice absorbs an average of , 12.00 h per day?* |
| Solution | (a)  (b)  (c) |
| 19. | *How many grams of coffee must evaporate from 350 g of coffee in a 100-g glass cup to cool the coffee from  to ? You may assume the coffee has the same thermal properties as water and that the average heat of vaporization is 2340 kJ/kg (560 cal/g). (You may neglect the change in mass of the coffee as it cools, which will give you an answer that is slightly larger than correct.)* |
| Solution | The heat gained in evaporating the coffee equals the heat leaving the coffee and glass to lower its temperature, so that  where  is the mass of coffee that evaporates. Solving for the evaporated coffee gives: |
| 20. | *(a) It is difficult to extinguish a fire on a crude oil tanker, because each liter of crude oil releases  of energy when burned. To illustrate this difficulty, calculate the number of liters of water that must be expended to absorb the energy released by burning 1.00 L of crude oil, if the water has its temperature raised from  to , it boils, and the resulting steam is raised to . (b) Discuss additional complications caused by the fact that crude oil has a smaller density than water.* |
| Solution | (a)    (b) Crude oil is less dense than water, so it floats on top of the water, thereby exposing it to the oxygen in the air, which it uses to burn. Also, if the water is under the oil, it is less able to absorb the heat generated by the oil. |
| 21. | *The energy released from condensation in thunderstorms can be very large. Calculate the energy released into the atmosphere for a small storm of radius 1 km, assuming that 1.0 cm of rain is precipitated uniformly over this area.* |
| Solution | We have a phase change . We need to find mass of rain in a cloud of radius 1 km. . With and , we find – about the energy released in the first atomic bomb explosion. |
| 22. | *To help prevent frost damage, 4.00 kg of*  *water is sprayed onto a fruit tree. (a) How much heat transfer occurs as the water freezes? (b) How much would the temperature of the 200-kg tree decrease if this amount of heat transferred from the tree? Take the specific heat to be , and assume that no phase change occurs.* |
| Solution | (a)  (b) |
| 23. | *A 0.250-kg aluminum bowl holding 0.800 kg of soup at*  *is placed in a freezer. What is the final temperature if 377 kJ of energy is transferred from the bowl and soup, assuming the soup’s thermal properties are the same as that of water? Explicitly show how you follow the steps in the Problem-Solving Strategies for the Effects of Heat Transfer.* |
| Solution | To bring the system to  requires heat, , of:  This leaves  to freeze all the soup, leaving  to be removed. So, we can now determine the final temperature of the frozen soup: |
| 24. | *A 0.0500-kg ice cube at*  *is placed in 0.400 kg of*  *water in a very well-insulated container. What is the final temperature?* |
| Solution | First bring the ice up to  and melt it with heat    This lowers the temperature of water by    Now, the heat lost by the hot water equals that gained by the cold water ( is the final temperature): |
| 25. | *If you pour 0.0100 kg of*  *water onto a 1.20-kg block of ice (which is initially at* *), what is the final temperature? You may assume that the water cools so rapidly that effects of the surroundings are negligible.* |
| Solution | First, we need to calculate how much heat would be required to raise the temperature of the ice to :  Now, we need to calculate how much heat is given off to lower the water to :  Since this is less than the heat required to heat the ice, we need to calculate how much heat is given off to convert the water to ice:  Thus, the total amount of heat given off to turn the water to ice at :  Since , we have determined that the final state of the water/ice is ice at some temperature below . Now, we need to calculate the final temperature. We set the heat lost from the water equal to the heat gained by the ice, where we now know that the final state is ice at :    Substituting for the change in temperatures (being careful that  is always positive) and simplifying gives:  Solving for the final temperature gives  and so finally, |
| 26. | *Indigenous people sometimes cook in watertight baskets by placing hot rocks into water to bring it to a boil. What mass of  rock must be placed in 4.00 kg of*  *water to bring its temperature to , if 0.0250 kg of water escapes as vapor from the initial sizzle? You may neglect the effects of the surroundings and take the average specific heat of the rocks to be that of granite.* |
| Solution | Let the subscripts r, e, v, and w represent rock, equilibrium, vapor, and water, respectively. |
| 27. | *What would be the final temperature of the pan and water in Calculating the Final Temperature When Heat Is Transferred Between Two Bodies: Pouring Cold Water in a Hot Pan if 0.260 kg of water was placed in the pan and 0.0100 kg of the water evaporated immediately, leaving the remainder to come to a common temperature with the pan?* |
| Solution | Let the subscripts Al, e, v, and w represent aluminum pan, equilibrium, vapor, and water, respectively. |
| 28. | *In some countries, liquid nitrogen is used on dairy trucks instead of mechanical refrigerators. A 3.00-hour delivery trip requires 200 L of liquid nitrogen, which has a density of . (a) Calculate the heat transfer necessary to evaporate this amount of liquid nitrogen and raise its temperature to* *. (Use  and assume it is constant over the temperature range.) This value is the amount of cooling the liquid nitrogen supplies. (b) What is this heat transfer rate in kilowatt-hours? (c) Compare the amount of cooling obtained from melting an identical mass of*  *ice with that from evaporating the liquid nitrogen.* |
| Solution | (a)  (b)  (c) |
| 29. | *Some gun fanciers make their own bullets, which involves melting and casting the lead slugs. How much heat transfer is needed to raise the temperature and melt 0.500 kg of lead, starting from* *?* |
| Solution |  |

# 14.5 Conduction

|  |  |  |  |
| --- | --- | --- | --- |
| 30. | | *(a) Calculate the rate of heat conduction through house walls that are 13.0 cm thick and that have an average thermal conductivity twice that of glass wool. Assume there are no windows or doors. The surface area of the walls is  and their inside surface is at* *, while their outside surface is at* *. (b) How many 1-kW room heaters would be needed to balance the heat transfer due to conduction?* | |
| Solution | | (a)  (b) 1 one-kilowatt room heater is needed. | |
| 31. | | *The rate of heat conduction out of a window on a winter day is rapid enough to chill the air next to it. To see just how rapidly the windows transfer heat by conduction, calculate the rate of conduction in watts through a  window that is  thick (1/4 in) if the temperatures of the inner and outer surfaces are*  *and* *, respectively. This rapid rate will not be maintained—the inner surface will cool, and even result in frost formation.* | |
| Solution | |  | |
| 32. | | *Calculate the rate of heat conduction out of the human body, assuming that the core internal temperature is* *, the skin temperature is* *, the thickness of the tissues between averages , and the surface area is .* | |
| Solution | |  | |
| 33. | | *Suppose you stand with one foot on ceramic flooring and one foot on a wool carpet, making contact over an area of  with each foot. Both the ceramic and the carpet are 2.00 cm thick and are*  *on their bottom sides. At what rate must heat transfer occur from each foot to keep the top of the ceramic and carpet at* *?* | |
| Solution | | For the wool carpet:    For the ceramic tile: | |
| 34. | *A man consumes 3000 kcal of food in one day, converting most of it to maintain body temperature. If he loses half this energy by evaporating water (through breathing and sweating), how many kilograms of water evaporate?* | |
| Solution | |  | |
| 35. | | *(a) A firewalker runs across a bed of hot coals without sustaining burns. Calculate the heat transferred by conduction into the sole of one foot of a firewalker given that the bottom of the foot is a 3.00-mm-thick callus with a conductivity at the low end of the range for wood and its density is . The area of contact is , the temperature of the coals is* *, and the time in contact is 1.00 s. (b) What temperature increase is produced in the  of tissue affected? (c) What effect do you think this will have on the tissue, keeping in mind that a callus is made of dead cells?* | |
| Solution | | (a)  (b) Taking the density of the callus to be , the change in temperature can be found from:    (c) At a temperature change of , the heat probably won’t do much damage, since a callus is made of dead cells. | |
| 36. | | *(a) What is the rate of heat conduction through the 3.00-cm-thick fur of a large animal having a  surface area? Assume that the animal’s skin temperature is* *, that the air temperature is* *, and that fur has the same thermal conductivity as air. (b) What food intake will the animal need in one day to replace this heat transfer?* | |
| Solution | | (a)  (b) | |
| 37. | | *A walrus transfers energy by conduction through its blubber at the rate of 150 W when immersed in*  *water. The walrus’s internal core temperature is* *, and it has a surface area of . What is the average thickness of its blubber, which has the conductivity of fatty tissues without blood?* | |
| Solution | |  | |
| 38. | | *Compare the rate of heat conduction through a 13.0-cm-thick wall that has an area of  and a thermal conductivity twice that of glass wool with the rate of heat conduction through a window that is 0.750 cm thick and that has an area of , assuming the same temperature difference across each.* | |
| Solution | | , so that | |
| 39. | | *Suppose a person is covered head to foot by wool clothing with average thickness of 2.00 cm and is transferring energy by conduction through the clothing at the rate of 50.0 W. What is the temperature difference across the clothing, given the surface area is ?* | |
| Solution | |  | |
| 40. | | *Some stove tops are smooth ceramic for easy cleaning. If the ceramic is 0.600 cm thick and heat conduction occurs through the same area and at the same rate as computed in Example 14.6, what is the temperature difference across it? Ceramic has the same thermal conductivity as glass and brick.* | |
| Solution | |  | |
| 41. | | *One easy way to reduce heating (and cooling) costs is to add extra insulation in the attic of a house. Suppose the house already had 15 cm of fiberglass insulation in the attic and in all the exterior surfaces. If you added an extra 8.0 cm of fiberglass to the attic, then by what percentage would the heating cost of the house drop? Take the single story house to be of dimensions 10 m by 15 m by 3.0 m. Ignore air infiltration and heat loss through windows and doors.* | |
| Solution | | The original heat loss by conduction is given by . We need to consider all 6 sides that contribute to the heat loss. We will put the loss through the attic in a separate part.    If we add 8 cm to the attic, the new addition is    So the percentage of savings in heat transfer =. | |
| 42. | | *(a) Calculate the rate of heat conduction through a double-paned window that has a  area and is made of two panes of 0.800-cm-thick glass separated by a 1.00-cm air gap. The inside surface temperature is* *, while that on the outside is* *. (Hint: There are identical temperature drops across the two glass panes. First find these and then the temperature drop across the air gap. This problem ignores the increased heat transfer in the air gap due to convection.) (b) Calculate the rate of heat conduction through a 1.60-cm-thick window of the same area and with the same temperatures. Compare your answer with that for part (a).* | |
| Solution | | | In equilibrium, the heat flows across each “slab” are equal.  (a)  Adding two equations, we obtain:    Now, we have      Since  (b)  The single-pane window has a rate of heat conduction equal to 1969/83, or 24 times that of a double pane window. |
| 43. | | | *Many decisions are made on the basis of the payback period: the time it will take through savings to equal the capital cost of an investment. Acceptable payback times depend upon the business or philosophy one has. (For some industries, a payback period is as small as two years.) Suppose you wish to install the extra insulation in Problem 14.41. If energy cost $1.00 per million joules and the insulation was $4.00 per square meter, then calculate the simple payback time. Take the average  for the 120 day heating season to be* *.* |
| Solution | | | We found in Problem 14.41 that  as baseline energy use. So the total heat loss during this period is .  At the cost of $1/MJ, the cost is $1960. From Problem 14.41, the savings is 12% or . We need of insulation in the attic. At  this is a $600 cost. So the payback period is . |
| 44. | | | *For the human body, what is the rate of heat transfer by conduction through the body’s tissue with the following conditions: the tissue thickness is 3.00 cm, the change in temperature is* *, and the skin area is . How does this compare with the average heat transfer rate to the body resulting from an energy intake of about 2400 kcal per day? (No exercise is included.)* |
| Solution | | | The rate of heat transfer by conduction is    On a daily basis, this is 1,728 kJ/day.  Daily food intake is  So only  of energy intake goes as heat transfer by conduction to the environment at this . |

# 14.6 Convection

|  |  |
| --- | --- |
| 45. | *At what wind speed does*  *air cause the same chill factor as still air at* *?* |
| Solution | 10 m/s (from Table 14.4) |
| 46. | *At what temperature does still air cause the same chill factor as*  *air moving at 15 m/s?* |
| Solution | (from Table 14.4) |
| 47. | *The “steam” above a freshly made cup of instant coffee is really water vapor droplets condensing after evaporating from the hot coffee. What is the final temperature of 250 g of hot coffee initially at*  *if 2.00 g evaporates from it? The coffee is in a Styrofoam cup, so other methods of heat transfer can be neglected.* |
| Solution | Let  be the mass of coffee that is left after evaporation and be the mass of coffee that evaporates. |
| 48. | *(a) How many kilograms of water must evaporate from a 60.0-kg woman to lower her body temperature by* *? (b) Is this a reasonable amount of water to evaporate in the form of perspiration, assuming the relative humidity of the surrounding air is low?* |
| Solution | (a) is the mass of the woman and is the mass of water that evaporates:    (b) Yes, 64.4 g of water is reasonable. If the air is very dry, the sweat may evaporate without even being noticed. |
| 49. | *On a hot dry day, evaporation from a lake has just enough heat transfer to balance the  of incoming heat from the Sun. What mass of water evaporates in 1.00 h from each square meter? Explicitly show how you follow the steps in the Problem-Solving Strategies for the Effects of Heat Transfer.* |
| Solution | (Note that we can use the  value at  as a closer approximation of the temperature on a hot day than .) |
| 50. | *One winter day, the climate control system of a large university classroom building malfunctions. As a result, of excess cold air is brought in each minute. At what rate in kilowatts must heat transfer occur to warm this air by*  *(that is, to bring the air to room temperature)?* |
| Solution |  |
| 51. | *The Kilauea volcano in Hawaii is the world’s most active, disgorging about  of*  *lava per day. What is the rate of heat transfer out of Earth by convection if this lava has a density of  and eventually cools to* *? Assume that the specific heat of lava is the same as that of granite.* |
| Solution | For *c*, we use the specific heat of granite, which is formerly molten rock. |
| 52. | *During heavy exercise, the body pumps 2.00 L of blood per minute to the surface, where it is cooled by* *. What is the rate of heat transfer from this forced convection alone, assuming blood has the same specific heat as water and its density is ?* |
| Solution |  |
| 53. | *A person inhales and exhales 2.00 L of*  *air, evaporating  of water from the lungs and breathing passages with each breath. (a) How much heat transfer occurs due to evaporation in each breath? (b) What is the rate of heat transfer in watts if the person is breathing at a moderate rate of 18.0 breaths per minute? (c) If the inhaled air had a temperature of* *, what is the rate of heat transfer for warming the air? (d) Discuss the total rate of heat transfer as it relates to typical metabolic rates. Will this breathing be a major form of heat transfer for this person?* |
| Solution | (a)  (b)  (c)  (d) The total rate of heat loss would be 29.2 W + 9.49 W = 38.7 W. While sleeping, our body consumes 83 W of power, while sitting it ranges 120-210 W. Therefore, the total rate of heat loss from breathing will not be a major form of heat loss for this person. |
| 54. | *A glass coffee pot has a circular bottom with a 9.00-cm diameter in contact with a heating element that keeps the coffee warm with a continuous heat transfer rate of 50.0 W. (a) What is the temperature of the bottom of the pot, if it is 3.00 mm thick and the inside temperature is* *? (b) If the temperature of the coffee remains constant and all of the heat transfer is removed by evaporation, how many grams per minute evaporate? Take the heat of vaporization to be 2340 kJ/kg.* |
| Solution | (a)  (b) |

# 14.7 Radiation

|  |  |
| --- | --- |
| 55. | *At what net rate does heat radiate from a  black roof on a night when the roof’s temperature is*  *and the surrounding temperature is* *? The emissivity of the roof is 0.900.* |
| Solution | Note that the negative answer implies heat loss to the surroundings. |
| 56. | *(a) Cherry-red embers in a fireplace are at*  *and have an exposed area of  and an emissivity of 0.980. The surrounding room has a temperature of* *. If 50% of the radiant energy enters the room, what is the net rate of radiant heat transfer in kilowatts? (b) Does your answer support the contention that most of the heat transfer into a room by a fireplace comes from infrared radiation?* |
| Solution | (a)  Note that the negative answer implies heat loss to the surroundings.  (b) This answer is quite large, so it does indeed suggest that the heat put into a room by a fireplace comes mainly from infrared radiation (which is hotter than red embers). |
| 57. | *Radiation makes it impossible to stand close to a hot lava flow. Calculate the rate of heat transfer by radiation from  of*  *fresh lava into*  *surroundings, assuming lava’s emissivity is 1.00.* |
| Solution |  |
| 58. | *(a) Calculate the rate of heat transfer by radiation from a car radiator at*  *into a*  *environment, if the radiator has an emissivity of 0.750 and a  surface area. (b) Is this a significant fraction of the heat transfer by an automobile engine? To answer this, assume a horsepower of 200 hp (1.5 kW) and the efficiency of automobile engines as* *.* |
| Solution | (a)  (b) Assuming an automobile engine is 200 horsepower and the efficiency of a gasoline engine is 25%, the engine consumes  Therefore, 600 horsepower is lost due to heating. The radiator transfers  from radiation, which is not a significant fraction because the heat is primarily transferred from the radiator by other means. |
| 59. | *Find the net rate of heat transfer by radiation from a skier standing in the shade, given the following. She is completely clothed in white (head to foot, including a ski mask), the clothes have an emissivity of 0.200 and a surface temperature of* *, the surroundings are at* *, and her surface area is .* |
| Solution |  |
| 60. | *Suppose you walk into a sauna that has an ambient temperature of* *. (a) Calculate the rate of heat transfer to you by radiation given your skin temperature is*  *, the emissivity of skin is 0.98, and the surface area of your body is . (b) If all other forms of heat transfer are balanced (the net heat transfer is zero), at what rate will your body temperature increase if your mass is 75.0 kg?* |
| Solution | (a)  (b) |
| 61. | *Thermography is a technique for measuring radiant heat and detecting variations in surface temperatures that may be medically, environmentally, or militarily meaningful.(a) What is the percent increase in the rate of heat transfer by radiation from a given area at a temperature of*  *compared with that at* *, such as on a person’s skin? (b) What is the percent increase in the rate of heat transfer by radiation from a given area at a temperature of*  *compared with that at* *, such as for warm and cool automobile hoods?* |
| Solution | (a)  (b) |
| 62. | *The Sun radiates like a perfect black body with an emissivity of exactly 1. (a) Calculate the surface temperature of the Sun, given that it is a sphere with a  radius that radiates  into 3-K space. (b) How much power does the Sun radiate per square meter of its surface? (c) How much power in watts per square meter is that value at the distance of Earth, away? (This number is called the solar constant.)* |
| Solution | (a)  (b)  (c) Let  be the radius of a sphere with the sun at the center and the earth at a point on the surface of the sphere. |
| 63. | *A large body of lava from a volcano has stopped flowing and is slowly cooling. The interior of the lava is at* *, its surface is at* *, and the surroundings are at* *. (a) Calculate the rate at which energy is transferred by radiation from  of surface lava into the surroundings, assuming the emissivity is 1.00. (b) Suppose heat conduction to the surface occurs at the same rate. What is the thickness of the lava between the*  *surface and the*  *interior, assuming that the lava’s conductivity is the same as that of brick?* |
| Solution | (a)  Note the negative answer implies heat lost to the surroundings.  (b) |
| 64. | *Calculate the temperature the entire sky would have to be in order to transfer energy by radiation at —about the rate at which the Sun radiates when it is directly overhead on a clear day. This value is the effective temperature of the sky, a kind of average that takes account of the fact that the Sun occupies only a small part of the sky but is much hotter than the rest. Assume that the body receiving the energy has a temperature of* *.* |
| Solution |  |
| 65. | *(a) A shirtless rider under a circus tent feels the heat radiating from the sunlit portion of the tent. Calculate the temperature of the tent canvas based on the following information: The shirtless rider’s skin temperature is*  *and has an emissivity of 0.970. The exposed area of skin is . He receives radiation at the rate of 20.0 W—half what you would calculate if the entire region behind him was hot. The rest of the surroundings are at* *. (b) Discuss how this situation would change if the sunlit side of the tent was nearly pure white and if the rider was covered by a white tunic.* |
| Solution | (a)  (b) A pure white object reflects more of the radiant energy that hits it, so the white tent would prevent more of the sunlight from heating up the inside of the tent, and the white tunic would prevent that radiant energy inside the tent from heating the rider. Therefore, with a white tent, the temperature would be lower than , and the rate of radiant heat transferred to the rider would be less than 20.0 W. |
| 66. | ***Integrated Concepts*** *One*  *day the relative humidity is* *, and that evening the temperature drops to* *, well below the dew point. (a) How many grams of water condense from each cubic meter of air? (b) How much heat transfer occurs by this condensation? (c) What temperature increase could this cause in dry air?* |
| Solution | (a) Let  be the vapor density during the day. Percent relative humidity is equal to the vapor density divided by the saturation vapor density. Using the values for relative humidity and saturation vapor density, we have    (b)  (c) |
| 67. | ***Integrated Concepts*** *Large meteors sometimes strike the Earth, converting most of their kinetic energy into thermal energy. (a) What is the kinetic energy of a  meteor moving at 25.0 km/s? (b) If this meteor lands in a deep ocean and*  *of its kinetic energy goes into heating water, how many kilograms of water could it raise by*  *(c) Discuss how the energy of the meteor is more likely to be deposited in the ocean and the likely effects of that energy.* |
| Solution | (a)  (b)  (c) When a large meteor hits the ocean, it causes great tidal waves, dissipating a large amount of its energy in the form of kinetic energy of the water. |
| 68. | ***Integrated Concepts*** *Frozen waste from airplane toilets has sometimes been accidentally ejected at high altitude. Ordinarily it breaks up and disperses over a large area, but sometimes it holds together and strikes the ground. Calculate the mass of*  *ice that can be melted by the conversion of kinetic and gravitational potential energy when a  piece of frozen waste is released at 12.0 km altitude while moving at 250 m/s and strikes the ground at 100 m/s (since less than 20.0 kg melts, a significant mess results).* |
| Solution | Let  be the mass of the ice block and  be the mass that melts before hitting the ground. |
| 69. | ***Integrated Concepts*** *(a) A large electrical power facility produces 1600 MW of “waste heat,” which is dissipated to the environment in cooling towers by warming air flowing through the towers by* *. What is the necessary flow rate of air in ? (b) Is your result consistent with the large cooling towers used by many large electrical power plants?* |
| Solution | (a)  (b) This is equivalent to 12 million cubic feet of air per second. That is tremendous. This is too large to be dissipated by heating the air by only  . Many of these cooling towers use the circulation of cooler air over warmer water to increase the rate of evaporation. This would allow there to be much smaller amounts of air necessary to remove such a large amount of heat, because evaporation removes larger quantities of heat than was considered in part (a). |
| 70. | ***Integrated Concepts*** *(a) Suppose you start a workout on a Stairmaster, producing power at the same rate as climbing 116 stairs per minute. Assuming your mass is 76.0 kg and your efficiency is* *, how long will it take for your body temperature to rise*  *if all other forms of heat transfer in and out of your body are balanced? (b) Is this consistent with your experience in getting warm while exercising?* |
| Solution | (a) You produce power at a rate of 685 W, and since you are 20% efficient, you must have generated: .  If only 685 W of power was useful, the power available to heat the body is .  Now, so that  (b) This says that it takes about a minute and a half to generate enough heat to raise the temperature of your body by , which seems quite reasonable. Generally, within five minutes of working out on a Stairmaster, you definitely feel warm and probably are sweating to keep your body from overheating. |
| 71. | ***Integrated Concepts*** *A 76.0-kg person suffering from hypothermia comes indoors and shivers vigorously. How long does it take the heat transfer to increase the person’s body temperature by*  *if all other forms of heat transfer are balanced?* |
| Solution |  |
| 72. | ***Integrated Concepts*** *In certain large geographic regions, the underlying rock is hot. Wells can be drilled and water circulated through the rock for heat transfer for the generation of electricity. (a) Calculate the heat transfer that can be extracted by cooling  of granite by* *. (b) How long will it take for heat transfer at the rate of 300 MW, assuming no heat transfers back into the  of rock by its surroundings?* |
| Solution | (a)  (b) |
| 73. | ***Integrated Concepts*** *Heat transfers from your lungs and breathing passages by evaporating water. (a) Calculate the maximum number of grams of water that can be evaporated when you inhale 1.50 L of*  *air with an original relative humidity of 40.0%. (Assume that body temperature is also* *.) (b) How many joules of energy are required to evaporate this amount? (c) What is the rate of heat transfer in watts from this method, if you breathe at a normal resting rate of 10.0 breaths per minute?* |
| Solution | (a) To solve this, we calculate the mass of water initially in the breath and subtract this value from the mass of the water in an exhaled breath at 100% humidity. Using the saturation vapor density of water at ,    (b)  (Note thatfor water at  is used here as a better approximation than for water at )  (c) |
| 74. | ***Integrated Concepts*** *(a) What is the temperature increase of water falling 55.0 m over Niagara Falls? (b) What fraction must evaporate to keep the temperature constant?* |
| Solution | (a)  (b) Let  be the mass of water that evaporates.  (Note that  for water at  is used here as a better approximation than for water at ) |
| 75. | ***Integrated Concepts*** *Hot air rises because it has expanded. It then displaces a greater volume of cold air, which increases the buoyant force on it. (a) Calculate the ratio of the buoyant force to the weight of*  *air surrounded by*  *air. (b) What energy is needed to cause  of air to go from*  *to*  *(c) What gravitational potential energy is gained by this volume of air if it rises 1.00 m? Will this cause a significant cooling of the air?* |
| Solution | (a)  The density of a given volume of air will be proportional to .    The buoyant force is equal to the weight of the displaced cold air (Archimedes’ principle.) Thus,    (b)  (c)  This will not cause a significant cooling of the air because it is much less than the energy found in part (b), which is the energy required to warm the air from  to . |
| 76. | ***Unreasonable Results*** *(a) What is the temperature increase of an 80.0 kg person who consumes 2500 kcal of food in one day with*  *of the energy transferred as heat to the body? (b) What is unreasonable about this result? (c) Which premise or assumption is responsible?* |
| Solution | (a)  This says that the temperature of the person is  (b) Any temperature increase greater than about  would be unreasonably large. In this case the final temperature of the person would rise to .  (c) The assumption that the person retains 95% of the energy as body heat is unreasonable. Most of the food consumed on a day is converted to body heat, losing energy by sweating and breathing, etc. |
| 77. | ***Unreasonable Results*** *A slightly deranged Arctic inventor surrounded by ice thinks it would be much less mechanically complex to cool a car engine by melting ice on it than by having a water-cooled system with a radiator, water pump, antifreeze, and so on. (a) If*  *of the energy in 1.00 gal of gasoline is converted into “waste heat” in a car engine, how many kilograms of*  *ice could it melt? (b) Is this a reasonable amount of ice to carry around to cool the engine for 1.00 gal of gasoline consumption? (c) What premises or assumptions are unreasonable?* |
| Solution | (a)  (b) No, the mass of ice is greater than 1/4 of a ton.  (c) Not all waste heat goes into the engine. |
| 78. | ***Unreasonable Results*** *(a) Calculate the rate of heat transfer by conduction through a window with an area of  that is 0.750 cm thick, if its inner surface is at*  *and its outer surface is at* *. (b) What is unreasonable about this result? (c) Which premise or assumption is responsible?* |
| Solution | (a)  (b) This is very high power loss through a window. An electric heater of this power can keep an entire room warm.  (c) The surface temperatures of the window do not differ by as great an amount as assumed. The inner surface will be warmer, and the outer surface will be cooler. |
| 79. | ***Unreasonable Results*** *A meteorite 1.20 cm in diameter is so hot immediately after penetrating the atmosphere that it radiates 20.0 kW of power. (a) What is its temperature, if the surroundings are at*  *and it has an emissivity of 0.800? (b) What is unreasonable about this result? (c) Which premise or assumption is responsible?* |
| Solution | (a) Given (Note that the negative sign indicates that the meteorite radiates heat to the surroundings.)    (b) The meteorite has too high a temperature. It would completely melt.  (c) The rate of radiation is probably too high. |

# Test Prep For AP® Courses

|  |  |
| --- | --- |
| 1. | *An ice cube is placed in a cup of hot water. Which of the following statements correctly describes energy transfer at the molecular level?*  (a) Kinetic energy is transferred only from the hot water molecules to the water molecules in the ice.  (b) Kinetic energy is transferred only from the water molecules in the ice to the hot water molecules.  (c) Kinetic energy is transferred mostly from the hot water molecules to the water molecules in the ice.  (d) Kinetic energy is transferred mostly from the water molecules in the ice to the hot water molecules. |
| Solution | (c) |
| 2. | *The molecular description of heat transfer from higher to lower temperatures applies to ‘spontaneous’ processes, that is, processes in which no energy is added or removed to or from the systems by work or heat. Refrigeration is an example of work being done to remove energy from air within a given space, and thus lower the temperature of the air. Assume a typical kitchen refrigerator, where the air inside the unit forms the system with a temperature of 25°C, and the walls are kept at a constant temperature of 10°C. In terms of molecules and average kinetic energy, describe how the air is made colder.* |
| Solution | The various molecules in the air have a higher average kinetic energy than the particles in the walls and so give up some of that energy to those particles. This causes the temperature of the air to gradually decrease. Work is done by the refrigeration system to keep the walls at the same temperature, so the particles in the walls maintain the same average kinetic energy, even after collisions with the molecules in the air. With further collisions, more energy is given up by the air to the walls of the refrigerator, until both have the same temperature (thermal equilibrium). |
| 3. | *For the experiment above that you devised, which variables can be changed, and how should they be changed, so as to shorten the time in which a measurement is made?*  (a) Use a smaller quantity of ice (smaller m).  (b) Use containers with greater thickness (larger d).  (c) Use containers with smaller surface areas (smaller A).  (d) Use a lower ambient temperature outside the container (smaller T2). |
| Solution | (a) |
| 4. | *Why does the change in the temperature of the ice indicate that it has entirely melted?* |
| Solution | All energy transfer by heat from the incubator to the ice is used to change the phase of the ice from solid to liquid water. Only when all of the bonds that hold the water molecules in the solid state are broken (as indicated by the mass of the ice and the latent heat of fusion for ice) can energy be absorbed by the liquid water to increase the kinetic energy of the water molecules. This increase in the average kinetic energy of the molecules is measured as an increase in temperature. |
| 5. | *Which of the following correctly describes the rate of conductive heat transfer for a substance?*  (a) The rate decreases with increased surface area and decreased thickness.  (b) The rate increases with increased temperature difference and surface area.  (c) The rate increases with decreased temperature difference and increased thickness.  (d) The rate decreases with decreased temperature difference and increased surface area. |
| Solution | (b) |
| 6. | *You wish to design a saucepan that has the same rate of thermal conduction as a pan made of silver. You need to use a less costly material, and limit the size of the pan so that the surface area in contact with a range heating element is no more than 50% greater than that of the hypothetical silver pan. Explain what other factor(s) can be adjusted, and by how much, so that your design will be successful. Use Table 14.3 to obtain thermal conductivity values for different substances.* |
| Solution | Answers use the equation for thermal conductivity for silver and for an alternate metal, noting that Q/t and (T2 ‒ T1) are the same for both metals. Possible answers include (1) use copper for the pan, because it is cheaper than silver (though not as cheap as aluminum or iron), and it only needs to be 1.08 times as large in surface area, with the same thickness as the silver pan; (2) design the copper pan to have the same area and be 0.93 times as thick as the silver pan; (3) use aluminum for the pan, make the area 1.5 times as large as that of the silver pan, and reduce the thickness to  times that of the silver pan; and (4) use steel iron for the pan, make the area 1.5 times as large as that of the silver pan, and reduce the thickness to  times that of the silver pan. |
| 7. | *Under which two conditions would convection in a fluid be greatest?*  (a) The gravitational acceleration is large, and the fluid density varies greatly for a given temperature change.  (b) The gravitational acceleration is small, and the fluid density varies greatly for a given temperature change.  (c) The gravitational acceleration is large, and the fluid density varies slightly for a given temperature change.  (d) The gravitational acceleration is small, and the fluid density varies slightly for a given temperature change. |
| Solution | (a) |
| 8. | *Sea breezes occur along coastlines, and consist of cool air moving toward the shore from the ocean. However, this only occurs during the day, and is a stronger effect when the air temperature on the land is greatest and the air temperature above the water is coldest. At night, the breezes are reversed, moving from the land toward the ocean. Taking into consideration the specific heat capacities of water and sand (which is about the same as that of concrete), explain how sea breezes form during the day and change direction at night.* |
| Solution | Water has a greater specific heat capacity than sand does, and so for a given amount of energy from sunlight, its temperature does not rise as much as does that of the sand. The sand therefore gives up more energy than does the ocean water to the air above. This means that the air above land has a higher temperature, and so expands, which in turn gives it a lower density than the air over the water. Through convection, the warm air rises upward, and the cool air from the ocean moves in, forming the sea breeze. At night, the process reverses, because the temperature of the sand decreases more than the temperature of the water does (again, because of the difference in specific heat capacities). The air above water is now less dense, and rises upward. The air over land moves outward to displace the rising sea air, forming a breeze that moves from land to sea. |
| 9. | *Two ideal, black-body radiators have temperatures of 275 K and 1100 K. The rate of heat transfer from the latter radiator is how many times greater than the rate of the former radiator?*  (a) 4  (b) 16  (c) 64  (d) 256 |
| Solution | (d) |
| 10. | *On a warm, sunny day, a car is parked along a street where there is no shade. The car’s windows are closed. The air inside the car becomes noticeably warmer than the air outside. What factors contribute to the higher temperature?* |
| Solution | Electromagnetic radiation from the Sun enters the car and is absorbed by the materials (such as the upholstery) inside. At the same time, the interior materials of the car, such as the glass of the windows and windshield, insulate the air inside the car, and so reduce heat transfer by conduction. The sealed interior of the car also prevents circulation of air by convection. |

This file is copyright 2015, Rice University. All Rights Reserved.