

14.E: Heat and Heat Transfer Methods (Exercise)

Conceptual Questions

14.1: Heat

1. How is heat transfer related to temperature?
2. Describe a situation in which heat transfer occurs. What are the resulting forms of energy?
3. When heat transfers into a system, is the energy stored as heat? Explain briefly.

14.2: Temperature Change and Heat Capacity

4. What three factors affect the heat transfer that is necessary to change an object's temperature?
5. The brakes in a car increase in temperature by ΔT when bringing the car to rest from a speed v . How much greater would ΔT be if the car initially had twice the speed? You may assume the car to stop sufficiently fast so that no heat transfers out of the brakes.

14.3: Phase Change and Latent Heat

6. Heat transfer can cause temperature and phase changes. What else can cause these changes?
7. How does the latent heat of fusion of water help slow the decrease of air temperatures, perhaps preventing temperatures from falling significantly below 0°C , in the vicinity of large bodies of water?
8. What is the temperature of ice right after it is formed by freezing water?
9. If you place 0°C ice into 0°C water in an insulated container, what will happen? Will some ice melt, will more water freeze, or will neither take place?
10. What effect does condensation on a glass of ice water have on the rate at which the ice melts? Will the condensation speed up the melting process or slow it down?
11. In very humid climates where there are numerous bodies of water, such as in Florida, it is unusual for temperatures to rise above about $35^\circ\text{C}(95^\circ\text{F})$. In deserts, however, temperatures can rise far above this. Explain how the evaporation of water helps limit high temperatures in humid climates.
12. In winters, it is often warmer in San Francisco than in nearby Sacramento, 150 km inland. In summers, it is nearly always hotter in Sacramento. Explain how the bodies of water surrounding San Francisco moderate its extreme temperatures.
13. Putting a lid on a boiling pot greatly reduces the heat transfer necessary to keep it boiling. Explain why.
14. Freeze-dried foods have been dehydrated in a vacuum. During the process, the food freezes and must be heated to facilitate dehydration. Explain both how the vacuum speeds up dehydration and why the food freezes as a result.
15. When still air cools by radiating at night, it is unusual for temperatures to fall below the dew point. Explain why.
16. In a physics classroom demonstration, an instructor inflates a balloon by mouth and then cools it in liquid nitrogen. When cold, the shrunken balloon has a small amount of light blue liquid in it, as well as some snow-like crystals. As it warms up, the liquid boils, and part of the crystals sublimate, with some crystals lingering for awhile and then producing a liquid. Identify the blue liquid and the two solids in the cold balloon. Justify your identifications using data from Table.

14.4: Heat Transfer Methods

17. What are the main methods of heat transfer from the hot core of Earth to its surface? From Earth's surface to outer space?

14.5: Conduction

18. Some electric stoves have a flat ceramic surface with heating elements hidden beneath. A pot placed over a heating element will be heated, while it is safe to touch the surface only a few centimeters away. Why is ceramic, with a conductivity less than that of a metal but greater than that of a good insulator, an ideal choice for the stove top?
19. Loose-fitting white clothing covering most of the body is ideal for desert dwellers, both in the hot Sun and during cold evenings. Explain how such clothing is advantageous during both day and night.



A jellabiya is worn by many men in Egypt. (credit: Zerida)

14.6: Convection

20. One way to make a fireplace more energy efficient is to have an external air supply for the combustion of its fuel. Another is to have room air circulate around the outside of the fire box and back into the room. Detail the methods of heat transfer involved in each.
21. On cold, clear nights horses will sleep under the cover of large trees. How does this help them keep warm?

14.7 Radiation

22. When watching a daytime circus in a large, dark-colored tent, you sense significant heat transfer from the tent. Explain why this occurs.
23. Satellites designed to observe the radiation from cold (3 K) dark space have sensors that are shaded from the Sun, Earth, and Moon and that are cooled to very low temperatures. Why must the sensors be at low temperature?
24. Why are cloudy nights generally warmer than clear ones?
25. Why are thermometers that are used in weather stations shielded from the sunshine? What does a thermometer measure if it is shielded from the sunshine and also if it is not?
26. On average, would Earth be warmer or cooler without the atmosphere? Explain your answer.

Problems & Exercises

14.2: Temperature Change and Heat Capacity

27. On a hot day, the temperature of an 80,000-L swimming pool increases by 1.50°C . What is the net heat transfer during this heating? Ignore any complications, such as loss of water by evaporation.

Solution

$$5.02 \times 10^8 \text{ J}$$

28. Show that $1 \text{ cal/g} \cdot ^{\circ}\text{C} = 1 \text{ kcal/kg} \cdot ^{\circ}\text{C}$.

29. To sterilize a 50.0-g glass baby bottle, we must raise its temperature from 22.0°C to 95.0°C . How much heat transfer is required?

Solution

$$3.07 \times 10^3 \text{ J}$$

30. 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 20.0°C .

- (a) water;
- (b) concrete;
- (c) steel; and

(d) mercury.

31. 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

0.171°C

32. A 0.250-kg block of a pure material is heated from 20.0°C to 65.0°C by the addition of 4.35 kJ of energy. Calculate its specific heat and identify the substance of which it is most likely composed.

33. 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

10.8

34. (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 54.9°C temperature increase?

(b) Compare your answer to labeling information found on a package of peanuts and comment on whether the values are consistent.

35. Following vigorous exercise, the body temperature of an 80.0-kg person is 40.0°C. At what rate in watts must the person transfer thermal energy to reduce the body temperature to 37.0°C in 30.0 min, assuming the body continues to produce energy at the rate of 150 W? (**1 watt = 1 joule/second or 1 W = 1 J/s**).

Solution

617 W

36. 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 (**1 watt = 1 joule/second or 1 W = 1 J/s and 1 MW = 1 megawatt**).

(a) Calculate the rate of temperature increase in degrees Celsius per second (°C/s) if the mass of the reactor core is $1.60 \times 10^5 \text{ kg}$ and it has an average specific heat of $0.3349 \text{ kJ/kg} \cdot \text{C}$.

(b) How long would it take to obtain a temperature increase of 2000°C, 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 $5 \times 10^5 \text{ kg}$ steel containment vessel would also begin to heat up.)

14.3: Phase Change and Latent Heat

37. How much heat transfer (in kilocalories) is required to thaw a 0.450-kg package of frozen vegetables originally at 0°C if their heat of fusion is the same as that of water?

Solution

35.9 kcal

38. A bag containing 0°C ice is much more effective in absorbing energy than one containing the same amount of 0°C water.

a. How much heat transfer is necessary to raise the temperature of 0.800 kg of water from 0°C to 30.0°C?

b. How much heat transfer is required to first melt 0.800 kg of 0°C ice and then raise its temperature?

c. Explain how your answer supports the contention that the ice is more effective.

39. (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 30.0°C 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 **1 watt = 1 joule/second (1 W = 1 J/s)**?

Solution

- (a) 591 kcal
- (b) $4.94 \times 10^3 \text{ s}$

40. 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.

41. 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 0°C and completely melts to 0°C water in exactly one day **1 watt = 1 joule/second (1 W = 1 J/s)**?

Solution

13.5 W

42. On a certain dry sunny day, a swimming pool's temperature would rise by 1.50°C if not for evaporation. What fraction of the water must evaporate to carry away precisely enough energy to keep the temperature constant?

43. (a) How much heat transfer is necessary to raise the temperature of a 0.200-kg piece of ice from -20.0°C to 130°C , 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) 148 kcal
- (b) 0.418 s, 3.34 s, 4.19 s, 22.6 s, 0.456 s

44. 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 917 kg/m^3 ?
- (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 100 W/m^2 , 12.00 h per day?

45. How many grams of coffee must evaporate from 350 g of coffee in a 100-g glass cup to cool the coffee from 95.0°C to 45.0°C ? 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

33.0 g

46. (a) It is difficult to extinguish a fire on a crude oil tanker, because each liter of crude oil releases $2.80 \times 10^7 \text{ J}$ 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 20.0°C to 100°C , it boils, and the resulting steam is raised to 300°C .

- (b) Discuss additional complications caused by the fact that crude oil has a smaller density than water.

Solution

- (a) 9.67 L
- (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 efficient in absorbing the heat generated by the oil.

47. 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.

48. To help prevent frost damage, 4.00 kg of 0°C 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 $3.35 \text{ kJ/kg} \cdot ^\circ\text{C}$, and assume that no phase change occurs.

Solution

- a) 319 kcal
- b) 2.00°C

49. A 0.250-kg aluminum bowl holding 0.800 kg of soup at 25.0°C 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 Problem-Solving Strategies for the Effects of Heat Transfer.

50. A 0.0500-kg ice cube at -30.0°C is placed in 0.400 kg of 35.0°C water in a very well-insulated container. What is the final temperature?

Solution

20.6°C

51. If you pour 0.0100 kg of 20.0°C water onto a 1.20-kg block of ice (which is initially at -15.0°C), what is the final temperature? You may assume that the water cools so rapidly that effects of the surroundings are negligible.

52. Indigenous people sometimes cook in watertight baskets by placing hot rocks into water to bring it to a boil. What mass of 500°C rock must be placed in 4.00 kg of 15.0°C water to bring its temperature to 100°C , 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

4.38 kg

53. 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?

54. 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 808 kg/m^3 .

(a) Calculate the heat transfer necessary to evaporate this amount of liquid nitrogen and raise its temperature to 3.00°C . (Use c_p 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 0°C ice with that from evaporating the liquid nitrogen.

Solution

- (a) $1.57 \times 10^4 \text{ kcal}$
- (b) $18.3 \text{ kW} \cdot \text{h}$
- (c) $1.29 \times 10^4 \text{ kcal}$

55. 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 25.0°C ?

14.5: Conduction

56. (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 120 m^2 and their inside surface is at 18.0°C , while their outside surface is at 5.00°C .

(b) How many 1-kW room heaters would be needed to balance the heat transfer due to conduction?

Solution

- (a) $1.01 \times 10^3 \text{ W}$
- (b) One

57. 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 3.00 m^2 window that is 0.635 cm thick ($1/4\text{ in}$) if the temperatures of the inner and outer surfaces are 5.00°C and -10.0°C , respectively. This rapid rate will not be maintained—the inner surface will cool, and even result in frost formation.

58. Calculate the rate of heat conduction out of the human body, assuming that the core internal temperature is 37.0°C , the skin temperature is 34.0°C , the thickness of the tissues between averages 1.00 cm , and the surface area is 1.40 m^2 .

Solution

84.0 W

59. Suppose you stand with one foot on ceramic flooring and one foot on a wool carpet, making contact over an area of 80.0 cm^2 with each foot. Both the ceramic and the carpet are 2.00 cm thick and are 10.0°C on their bottom sides. At what rate must heat transfer occur from each foot to keep the top of the ceramic and carpet at 33.0°C ?

60. 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

2.59 kg

61. (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 300 kg/m^3 . The area of contact is 25.0 cm^2 , the temperature of the coals is 700°C , and the time in contact is 1.00 s .

(b) What temperature increase is produced in the 25.0 cm^3 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?

62. (a) What is the rate of heat conduction through the 3.00-cm-thick fur of a large animal having a 1.40 m^2 surface area? Assume that the animal's skin temperature is 32.0°C , that the air temperature is -5.00°C , 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) 39.7 W

(b) 820 kcal

63. A walrus transfers energy by conduction through its blubber at the rate of 150 W when immersed in -1.00°C water. The walrus's internal core temperature is 37.0°C , and it has a surface area of 2.00 m^2 . What is the average thickness of its blubber, which has the conductivity of fatty tissues without blood?



Walrus on ice. (credit: Captain Budd Christman, NOAA Corps)

64. Compare the rate of heat conduction through a 13.0-cm-thick wall that has an area of 10.0 m^2 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 2.00 m^2 , assuming the same temperature difference across each.

Solution

35 to 1, window to wall

65. 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 1.40m^2 ?

66. 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, what is the temperature difference across it? Ceramic has the same thermal conductivity as glass and brick.

Solution

$$1.05 \times 10^3 K$$

67. 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.

68. (a) Calculate the rate of heat conduction through a double-paned window that has a $1.50 - \text{m}^2$ 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 15.0°C , while that on the outside is -10.0°C . (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

(a) 83 W

(b) 24 times that of a double pane window.

69. 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 Exercise. 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 ΔT for the 120 day heating season to be 15.0°C .

70. 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 2.00°C , and the skin area is 1.50m^2 . 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

20.0 W, 17.2% of 2400 kcal per day

14.6: Convection

71. At what wind speed does -10°C air cause the same chill factor as still air at -29°C ?

Solution

10 m/s

72. At what temperature does still air cause the same chill factor as -5°C air moving at 15 m/s?

73. 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 90.0°C if 2.00 g evaporates from it? The coffee is in a Styrofoam cup, so other methods of heat transfer can be neglected.

Solution

85.7°C

74. (a) How many kilograms of water must evaporate from a 60.0-kg woman to lower her body temperature by 0.750°C ?

(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?

75. On a hot dry day, evaporation from a lake has just enough heat transfer to balance the $1.00\text{kW}/\text{m}^2$ 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

1.48 kg

76. One winter day, the climate control system of a large university classroom building malfunctions. As a result, 500m^3 of excess cold air is brought in each minute. At what rate in kilowatts must heat transfer occur to warm this air by 10.0°C (that is, to bring the air to room temperature)?

77. The Kilauea volcano in Hawaii is the world's most active, disgorging about $5 \times 10^5\text{m}^3$ of 1200°C lava per day. What is the rate of heat transfer out of Earth by convection if this lava has a density of $2700\text{kg}/\text{m}^3$ and eventually cools to 30°C ? Assume that the specific heat of lava is the same as that of granite.



Lava flow on Kilauea volcano in Hawaii. (credit: J. P. Eaton, U.S. Geological Survey)

Solution

$2 \times 10^4\text{MW}$

78. During heavy exercise, the body pumps 2.00 L of blood per minute to the surface, where it is cooled by 2.00°C . 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 $1050\text{kg}/\text{m}^3$?

79. A person inhales and exhales 2.00 L of 37.0°C air, evaporating $4.00 \times 10^{-2}\text{g}$ of water from the lungs and breathing passages with each breath.

- How much heat transfer occurs due to evaporation in each breath?
- What is the rate of heat transfer in watts if the person is breathing at a moderate rate of 18.0 breaths per minute?
- If the inhaled air had a temperature of 20.0°C , what is the rate of heat transfer for warming the air?
- 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) 97.2 J

(b) 29.2 W

(c) 9.49 W

(d) The total rate of heat loss would be $29.2\text{W} + 9.49\text{W} = 38.7\text{W}$. While sleeping, our body consumes 83 W of power, while sitting it consumes 120 to 210 W. Therefore, the total rate of heat loss from breathing will not be a major form of heat loss for this person.

80. 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

- What is the temperature of the bottom of the pot, if it is 3.00 mm thick and the inside temperature is 60.0°C ?
- 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.

14.7 Radiation

81. At what net rate does heat radiate from a 275m^2 black roof on a night when the roof's temperature is 30.0°C and the surrounding temperature is 15.0°C ? The emissivity of the roof is 0.900.

Solution

-21.7 kW

Note that the negative answer implies heat loss to the surroundings.

82. (a) Cherry-red embers in a fireplace are at 850°C and have an exposed area of 0.200 m^2 and an emissivity of 0.980. The surrounding room has a temperature of 18.0°C . 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?

83. Radiation makes it impossible to stand close to a hot lava flow. Calculate the rate of heat transfer by radiation from 1.00 m^2 of 1200°C fresh lava into 30.0°C surroundings, assuming lava's emissivity is 1.00.

Solution

-266 kW

84. (a) Calculate the rate of heat transfer by radiation from a car radiator at 110°C into a 50.0°C environment, if the radiator has an emissivity of 0.750 and a 1.20 m^2 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 25%.

85. 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 10.0°C ; the surroundings are at -15.0°C , and her surface area is 1.60 m^2 .

Solution

-36.0 W

86. Suppose you walk into a sauna that has an ambient temperature of 50.0°C .

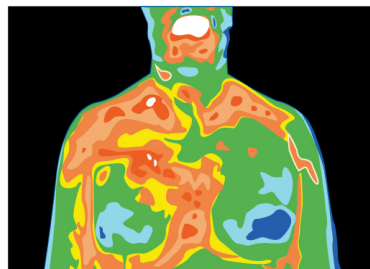
(a) Calculate the rate of heat transfer to you by radiation given your skin temperature is 37.0°C ; the emissivity of skin is 0.98, and the surface area of your body is 1.50 m^2 .

(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 ?

87. 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 34.0°C compared with that at 33.0°C , 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 34.0°C compared with that at 20.0°C , such as for warm and cool automobile hoods?



Artist's rendition of a thermograph of a patient's upper body, showing the distribution of heat represented by different colors.

Solution

(a) 1.31%

(b) 20.5%

88. 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 $7.00 \times 10^8 \text{ m}$ radius that radiates $3.80 \times 10^{26} \text{ W}$ 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, $1.50 \times 10^{11} \text{ m}$ away? (This number is called the solar constant.)

89. A large body of lava from a volcano has stopped flowing and is slowly cooling. The interior of the lava is at 1200°C , its surface is at 450°C , and the surroundings are at 27.0°C

- (a) Calculate the rate at which energy is transferred by radiation from 1.00 m^2 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 450°C surface and the 1200°C interior, assuming that the lava's conductivity is the same as that of brick?

Solution

- (a) -15.0 kW
- (b) 4.2 cm

90. Calculate the temperature the entire sky would have to be in order to transfer energy by radiation at 1000 W/m^2 —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 27.0°C .

91. (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 34.0°C and has an emissivity of 0.970. The exposed area of skin is 0.400 m^2 . 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 34.0°C .

- (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) 48.5°C
- (b) A pure white object reflects more of the radiant energy that hits it, so a white tent would prevent more of the sunlight from heating up the inside of the tent, and the white tunic would prevent that heat which entered the tent from heating the rider. Therefore, with a white tent, the temperature would be lower than 48.5°C , and the rate of radiant heat transferred to the rider would be less than 20.0 W .

92. Integrated Concepts

One 30.0°C day the relative humidity is 75.0, and that evening the temperature drops to 20.0°C , 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?

93. 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 10^9 kg meteor moving at 25.0 km/s ?
- (b) If this meteor lands in a deep ocean and 80 of its kinetic energy goes into heating water, how many kilograms of water could it raise by 5.0°C ?
- (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) $3 \times 10^{17} J$

(b) $1 \times 10^{13} kg$

(c) When a large meteor hits the ocean, it causes great tidal waves, dissipating large amount of its energy in the form of kinetic energy of the water.

94. 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 $0^\circ C$ ice that can be melted by the conversion of kinetic and gravitational potential energy when a 20.0 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).

95. 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 $5.00^\circ C$. What is the necessary flow rate of air in m^3/s ?

(b) Is your result consistent with the large cooling towers used by many large electrical power plants?

Solution

(a) $3.44 \times 10^5 m^3/s$

(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 $5^\circ C$. Many of these cooling towers use the circulation of cooler air over warmer water to increase the rate of evaporation. This would allow 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).

96. 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 20.0, how long will it take for your body temperature to rise $1.00^\circ C$ 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?

97. 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 $2.00^\circ C$ if all other forms of heat transfer are balanced?

Solution

20.9 min

98. 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 $1.00 km^3$ of granite by $100^\circ C$.

(b) How long will this take if heat is transferred at a rate of 300 MW, assuming no heat transfers back into the 1.00 km of rock by its surroundings?

99. 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 $37^\circ C$ air with an original relative humidity of 40.0%. (Assume that body temperature is also $37^\circ C$.)

(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) $3.96 \times 10^{-2} g$
- (b) $96.2 J$
- (c) $16.0 W$

100. 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?

101. 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 $50.0^\circ C$ air surrounded by $20.0^\circ C$ air. (b) What energy is needed to cause $1.00 m^3$ of air to go from $20.0^\circ C$ to $50.0^\circ C$? (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) 1.102
- (b) $2.79 \times 10^4 J$
- (c) 12.6 J. 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 $20.0^\circ C$ to $50.0^\circ C$

102. Unreasonable Results

- (a) What is the temperature increase of an 80.0 kg person who consumes 2500 kcal of food in one day with 95.0% 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) $36^\circ C$
- (b) Any temperature increase greater than about $3^\circ C$ would be unreasonably large. In this case the final temperature of the person would rise to $73^\circ C$ ($163^\circ F$).
- (c) The assumption of 95 heat retention is unreasonable.

103. 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 80.0% of the energy in 1.00 gal of gasoline is converted into “waste heat” in a car engine, how many kilograms of $0^\circ C$ 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?

104. Unreasonable Results

- (a) Calculate the rate of heat transfer by conduction through a window with an area of $1.00 m^2$ that is 0.750 cm thick, if its inner surface is at $22.0^\circ C$ and its outer surface is at $35.0^\circ C$.
- (b) What is unreasonable about this result?
- (c) Which premise or assumption is responsible?

Solution

- (a) 1.46 kW
- (b) 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.

105. *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 20.0°C and it has an emissivity of 0.800?
- (b) What is unreasonable about this result?
- (c) Which premise or assumption is responsible?

106. *Construct Your Own Problem*

Consider a new model of commercial airplane having its brakes tested as a part of the initial flight permission procedure. The airplane is brought to takeoff speed and then stopped with the brakes alone. Construct a problem in which you calculate the temperature increase of the brakes during this process. You may assume most of the kinetic energy of the airplane is converted to thermal energy in the brakes and surrounding materials, and that little escapes. Note that the brakes are expected to become so hot in this procedure that they ignite and, in order to pass the test, the airplane must be able to withstand the fire for some time without a general conflagration.

107. *Construct Your Own Problem*

Consider a person outdoors on a cold night. Construct a problem in which you calculate the rate of heat transfer from the person by all three heat transfer methods. Make the initial circumstances such that at rest the person will have a net heat transfer and then decide how much physical activity of a chosen type is necessary to balance the rate of heat transfer. Among the things to consider are the size of the person, type of clothing, initial metabolic rate, sky conditions, amount of water evaporated, and volume of air breathed. Of course, there are many other factors to consider and your instructor may wish to guide you in the assumptions made as well as the detail of analysis and method of presenting your results.

Contributors and Attributions

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