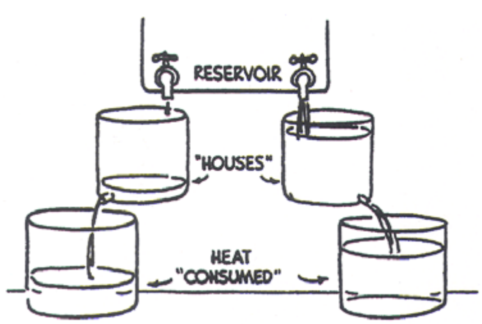
16 Heat Transfer

Helen Yan is a merit badge in my teaching career, as she continued from my Conceptual Physics class to a stellar career in space science. It is my pleasure that Helen's personal profile begins this chapter, and a nice touch to be able to show her photos two decades ago with newer ones doing the same demonstration. John Suchocki, my nephew, took the photo of the snow-covered mailboxes along his street. Your students may ask why the snow gathered on the lighter colored metal boxes and not on the black ones. If you answer this right away, you have a way to go before becoming a good teacher. With more teaching experience, you'll give an answer *after* your students have given it more thought. The black boxes, better absorbers, are somewhat warmer in sunlight or even an overcast day than the lighter boxes, so snow is more likely to melt upon the warmer black surfaces than the lighter ones. Hence snow accumulates more on the lighter mailboxes.

This chapter begins with conduction, convection and radiation of heat with emphasis again on bodies of water and the atmosphere. The section on radiation serves as some background to later chapters on light.

To turn your thermostat down or off in order to save energy, Think and Discuss 93, about whether to turn your thermostat down makes an excellent NEXT-TIME QUESTION. To illustrate its answer [turn it off], make up the apparatus shown, which consists of a main reservoir that feeds "heat" into two identical "houses," that leak heat to the environment. The amount of leakage is caught by the bottom jars and can be compared at a glance. Arrange the input flow rates so that equilibrium is established when the "houses" are nearly full: then input = outflow. Turn one input off altogether. After some time, turn it back on until it fills to the level of the other "house." Now compare the differences in leaked water! Make comparisons of turning it down partway instead of off. This roughly approximates Newton's law of cooling. Leak rate is highest when ΔT, or in this case, ΔP, is greatest.



Adiabatic expansion is suggested in this chapter, and a molecular model is described to account for the cooling that expanding air undergoes. This idea continues again in more detail in Chapter 18.

Firewalking: Charlatans still cite firewalking as overcoming nature. James Randi interestingly points out that when a charlatan is exposed, the outrage of his or her victims is most frequently aimed at the one who strips away the mask. And on the matter of nonsense, it seems unlikely that there will never be a claim so whacky that at least one PhD physicist cannot be found to vouch for it. There are fringies in every group—ours include.

Paul Doherty points out that unlike the decrease in temperature with distance about a hot coal or two, above a bed of coals the temperature remains fairly constant, like the constant electric field near a plane of charges.

Heat transfer is becoming more evident with concrete and glass buildings that absorb heat by day and release it by night. More transfer occurs with increases in temperatures, populations, and urbanization.

As more snow disappears, less sunlight is reflected into outer space, and world temperature increases. Hence rooftops should be painted white. Such reflective roofs would cut energy consumption by cooling buildings and reducing the need for air conditioners. Some of the greatest ideas are the simplest!

Cosmic microwave background (CMB), not treated in the chapter but mentioned in footnote 4 on page 311, was discovered in 1965 by Penzias and Wilson. CMB was emitted about 300,000 years after the Big Bang, when the universe was only one-thousandths of its present size. Today, CMB is one of cosmology's most important objects of study.

A discussion of the Earth's seasons is in order with this chapter. It is not covered in the text, but is an exercise in the Practice Book, pages 73 and 74, and relates to the section on Climate Change in this chapter.

Practicing Physics Book:
• Transmission of Heat

Problem Solving Book:
Heat problems, yes indeed!

Laboratory Manual:
• Canned Heat: Heating Up *Thermal Absorption* (Experiment)
• Canned Heat: Cooling Down *Thermal Absorption* (Experiment)
• I'm Melting, I'm Melting *Conduction and Absorption* (Demonstration)

Next-Time Questions:
• Firewalk
• Black or White Coffee
• Radiant Glow
• Winter Night
• Radiator
• Emitter
• Sleep Well
• Thermostat
• White House
• Equinox
• Black-Shiny Cookware
• Black-Shiny space Packaging
• How Warm or Cold

Hewitt-Drew-It! Screencasts: •*Heat Transfer* •*Radiant Energy*

SUGGESTED LECTURE PRESENTATION

Conduction: Begin by asking why pots and pans have wooden or plastic handles. Discuss conduction from an atomic point of view, citing the role of the electrons in both heat and electrical conductors. You might demonstrate the oldie of melting wax on different metal rods equidistance from a hot flame, and illustrate relative conductivities of the rods. Other materials can be compared in their ability to conduct heat, like newspaper when having to sleep out-of-doors. Discuss the poor conductivity of water, which ties to the discussion in the previous lecture of the 4°C temperature at the bottom of deep lakes all year round.

DEMONSTRATION: Do the activity suggested on page 307, of ice wedged at the bottom of a test tube. Some steel wool will hold the ice at the bottom of the tube. It is impressive to see that the water at the top is brought to a boil by the flame of a burner while the ice below barely melts!

DEMONSTRATION: Think and Do 33, at the end of the chapter on page 317 and wrap a piece of paper around a thick metal bar and attempt to burn it in the flame. The paper does not reach its ignition temperature because heat is conducted into the metal.

DEMONSTRATION: Extend the previous demo and lace a paper cup filled with water in the flame. Again, the paper will not reach its ignition temperature and burn because heat from the flame is conducted into the conductor—this time water. Water is not *that* poor a conductor—its high specific heat plays a role here also.

Discuss the poor conductivity of air, and its role in insulating materials—like snow. Discuss thermal underwear, and how the fish-net open spaces actually trap air between the skin and the undergarment. Discuss double-window thermopane. If your lecture was preceded by Chapter 14, cite the case of the manufacturer in the midwest who sent a shipment of thermopane windows by truck over the Rocky Mountains only to find that all the windows broke at the higher altitude. The atmospheric pressure between the panes was not matched by the same pressure outside. Ask if the windows "imploded" or "exploded." [Imploded.]

Convection and Rising Warm Air:

CHECK QUESTION: Why does smoke from a cigar rise and then settle off?

CHECK QUESTIONS: Why does helium rise to the very top of the atmosphere? Why doesn't it settle like the smoke? [Unlike the heated smoke, the helium molecule doesn't "cool off" and slow down when it interacts with the surrounding molecules. Due to its low mass, its average speed is higher than heavier molecules at the same temperature.]

After explaining that for the same temperature, the relatively small mass of helium is compensated for by a greater speed at whatever temperature and altitude, state that helium is not found in the air but must be mined from beneath the ground like natural gas. (The helium nucleus is the alpha particle that emanates from radioactive ores.) This idea of faster-moving helium underscores the relationship of kinetic energy to temperature. Stress it.

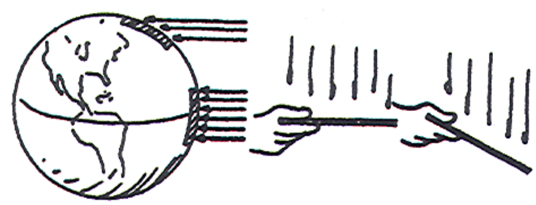
Expanding Air Cools: (The rising of warm air and its subsequent cooling is treated thermodynamically in Chapter 18—the treatment here and the later treatment complement each other nicely.) Now you're into the cooling effect of expanding air. Depart from the order of topics in the text and first treat the warming of compressed air. The familiar bicycle pump offers a good example. Why does the air become warm when the handle is depressed? It's easy to see that the air molecules speed up when the piston slams against them. A Ping-Pong ball similarly speeds up when a paddle hits it. Now, consider what happens to the speed of a Ping-Pong ball when it encounters a receding paddle! Can your students see that its rebound speed will be less than its incident speed? Now you're ready to discuss the cooling of expanding air, Figure 16.6, and compare this to the case of the slowing Ping-Pong balls with molecules that are on the average receding from one another.

Here's a great one: Have everyone in class blow against their hands with open mouths. Their breaths feel warm. Then repeat with mouth openings very small. Their breaths are remarkably cooler. They **experience** first hand that expanding air *really does* cool! (That's my son Paul in Figure 16.5, and his mom in Figure 16.7.)

DEMONSTRATION: Heat water in a pressure cooker, remove the cap and place your hand in the expanding steam that is ejected to show the cooling of expanding air, as Millie does in Figure 16.7. Mixing of water vapor with the outside air also contributes to this cooling. Cite that the students don't see steam as such, for the steam is actually not visible. The cloud they see is not steam but condensed water vapor—and considerably cooled!

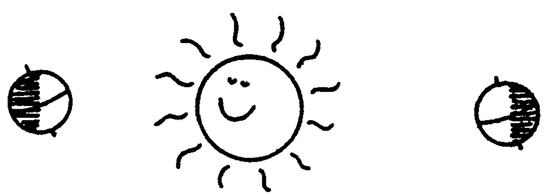
Discuss the role of convection in climates. Begin by calling attention to the shift in winds as shown in Figure 16.8. This leads you into radiation, the heat from the Sun.

Warm at the Equator — Cold at the Poles: You may want to discuss why the Earth is warmer at the equator than at the poles, and get into the idea of solar energy per unit area. A neat way to do this is to first draw a large circle on the board that represents Earth (like the one below, only without the Sun's rays at this point). Ask for a neighbor check and speculate why it is warm near the equator and cold at the poles. To dispel the idea that the farther distance to the poles is the reason, do the following:

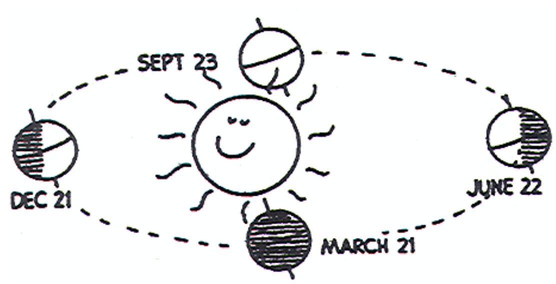


SKIT: Ask the class to pretend there is a vertical rainfall, into which you reach out your window with two sheets of paper—one held horizontally and the other held at an angle as shown. You bring the papers inside as a friend strolls by and inquires what you're doing. You remark that you have been holding the sheets of paper out in the rain. Your friend sees that the horizontally held paper is much wetter and asks why. You repeat with both papers held outward as before, and your friend says, "Oh, I see why. You're holding the tilted sheet farther away from the clouds!" Ask your class if you *are* holding it farther away from the overhead clouds. The answer is yes. Ask if this is the *reason* the paper is not as wet. The answer is no!

Seasons: (This is illustrated on Practice Page 74.) The plane of the Earth's equator is not parallel to the plane of the Earth's orbit. Instead, the polar axis is inclined at $23\frac{1}{2}$ degrees (the ecliptic). Draw the sketch below on the board, first with only the two positions of the Earth at the far left and far right. Ask which of these two positions represents winter months and which represents summer months. Encourage neighbor discussion.



Once it is clear that winter is at the left, show the position of the Earth in autumn and in spring. Shift the position of the Sun closer to the Earth in winter, for this is actually the case. From your drawing, your class can see why Northern Hemisphere types enjoy an extra week of spring and summer! Southern Hemisphere types are compensated by a somewhat milder climate year round due to the greater amount of ocean in the Southern Hemisphere (80% as compared to about 60% for the Northern Hemisphere).



Radiation: Discuss the radiation one feels from red hot coals in a fireplace. And how the radiation decreases with distance. Consider the radiation one feels when stepping from the shade to the sunshine. Amazing! The heat is not so much due to the Sun's temperature because like temperatures are to be found in the torches of some welders. One feels hot not because the Sun is hot, but because it is *big*. Comfortably big!

The equation $\bar{f} \sim T$ is nicely illustrated with an infra-red thermometer, Figure 16.15. (Available from Arbor Scientific, 68-6505.)

Everyone knows that the Sun radiates, and most people know the internal energy of the Sun involves nuclear processes—namely thermonuclear fusion. But relatively few people know that the same holds for planet Earth. The Earth's radiation, terrestrial radiation, is less intense and lower in frequency, but is nonetheless the same—electromagnetic radiation. The source of Earth's internal heat is also radioactive processes—mainly radioactive decay of uranium, thorium, and potassium (perhaps some fission, but certainly no thermonuclear fusion). Expand on these ideas—Figure 16.13 and one of the Next-Time Questions.

It should be surprising to your students that terrestrial radiation rather than solar radiation is directly responsible for the warmth of the air around us. Air is primarily warmed by the Earth, which is an important reason we don't freeze at night when we're not in the Sun's light.

Acknowledge that everything emits radiation—everything that has any temperature. But everything does not become progressively cooler because everything simultaneously absorbs radiation. Whether something is a net emitter or net absorber depends on the relative temperatures involved. In Figure 16.16, my buddy Dennis McNelis tastes the difference.

Acknowledge the role of smudge pots in an orchard. They create a cloud close to the ground, which enables terrestrial radiation a means of absorption and re-radiation back to the ground. This results in a longer cooling time for ground cooling, enabling more time to survive the night without freezing until sunlight comes to the rescue the following morning. Three cheers for terrestrial radiation!

We live in a sea of radiation, everything emitting and everything absorbing. When emission rate equals absorption rate, temperature remains constant. Some materials, because of their molecular design, emit better than others. They also absorb better than others. They're easy to spot because they absorb visible radiation as well and appear black.

> DEMONSTRATION: Make up and show the black hole in the white box, as shown by Helen Yan in the photo openers.

> DEMONSTRATION: Pour hot water into a pair of vessels, one black and the other shiny silver. Ask for a neighbor check as to which will cool faster. Have thermometers in each that you ask a student to read aloud at the beginning and a few minutes later. (You can repeat this demo with initially cold water in each vessel.)

Explain the frost in the above-freezing mornings bit described in the chapter on page 311.

> DEMONSTRATION: When a pair of heavy steel balls are smashed together, say by your hands, your class will see a smashing demonstration of energy dissipating to heat. The kinetic energy of the balls transforms into enough heat to burn a hole in a piece of paper. So do this while a student holds a sheet of paper where the balls will collide. A pair of 1 pound, 2-inch diameter chrome steel spheres is available from Arbor Scientific (P6-6070).

Newton's Law of Cooling: If you're into graphical analysis, construct a large plot of the exponential decrease of the temperature of either of the vessels in the previous demonstration. It's easy to see the curve is steep at first (when the water is hotter) and less steep as it cools. The slope of your curve is of changing temperature per time interval—the slope decreases as time increases. But one can as well say the slope decreases as the temperature approaches the ambient temperature. This is Newton's law of cooling.

The rate will be different for the black and silver vessels, so we see the difference between a proportionality sign and an equals sign for the formula here. The actual rate of cooling or warming is not only proportional to the difference in temperatures, but in the "emissivities" of the surfaces.

Relate Newton's law of cooling to Think and Discuss 92 (cream in the coffee), 93 (thermostat on a cold day), and 94 (air conditioner on a hot day). These exercises are excellent for class discussion.

Greenhouse Effect: As the text states, if there were no greenhouse effect, the average temperature of the Earth would be a frigid -18°C. So be glad that prayers are not answered that ask for an end to the greenhouse effect!

Compare the window glass of the florist's greenhouses to the carbon-dioxide window glass of the Earth's atmosphere. CO_2 builds up year by year by increased usage of fossil fuels that spew carbon into the atmosphere. Interestingly enough, the carbon that is spewed by burning is the same carbon that is absorbed by tree growth. So a realistic step in the solution to the greenhouse-effect problem is to simply grow more trees (while decreasing the rate at which they are cut down)! Johnny-Appleseed types—to the task! This would not be an end-all to the problem, however, because the carbon returns to the biosphere when the trees ultimately decay. More general than the term greenhouse effect is *global warming*, or more recently, *climate change*.

Interesting point: The Earth is always "in equilibrium" whether it is overheating or not. At a higher temperature that global warming produces, the Earth simply radiates more terrestrial radiation. Income and outgo match in any case; the important consideration is the temperature at which this income and outgo match.

Climate Change: I pose this question about global warming: How could the billions of tons of CO_2 pumped into the air by human activity *NOT* affect Earth's climate? I embrace the adage: You can't change only one thing.

Solar Power: Solar power has been with humans from the beginning. We see its application whenever we see clothes hung on a line (do you see that much anymore?) and we see it as an energy source on rooftops that provide hot water (Figure 16.25). And Lil's mom is shown utilizing solar power in Figure 16.26. Share up-to-date information on this growing technology with your class.

Excess Terrestrial Heat: Discuss the overheating of the Earth problem, with updates from the Internet.

As an interesting side point that pertains to heating, it has long been known that a frog cannot discern small changes in temperature, and if sitting comfortably in a pan of water that is slowly heated on a stove, it will make no effort to jump out as the water temperature increases. It will just sit there and be cooked. But this is not limited to frogs. According to accounts given by cannibals who cook their victims in large pots of water, the same is true of humans. Back in the 1970s in Mill Valley, CA, water in a hot tub gradually overheated (due to a faulty heater) and resulted in the deaths of the unsuspecting and drowsy individuals. You can compare this to other cases where if adverse conditions are increased gradually, humans will tolerate what otherwise would be completely unacceptable to them: smog, noise, pollution, crime, and so on.

Answers and Solutions for Chapter 16

Reading Check Questions

1. Loose electrons quickly move and transfer energy to other electrons that migrate through the material.
2. Conductivity of metals are much greater than conductivity of air.
3. Wood is a good insulator even when it's red hot, therefore very little thermal energy is transferred to the feet.
4. They are poor conductors, which makes them good insulators.
5. Insulation delays heat transfer.
6. Volume increases as air rises, and correspondingly cools.
7. Rebound speed increases; rebound speed decreases.
8. Speeds are increased with compression.
9. Speeds are decreased with expansion.
10. Her hand is not in steam, but in a jet of condensed vapor that has expanded and cooled.
11. Direction of winds change with changes in land and water temperatures. Air flow reverses as relative temperatures reverse.
12. Radiant energy travels in electromagnet waves.
13. High-frequency waves have short wavelengths.
14. Peak frequency and absolute temperature are directly proportional: $\bar{f} \sim T$.
15. Terrestrial radiation is that emitted by Earth's surface.
16. Terrestrial radiation is lower in frequency and intensity than solar radiation.
17. Temperatures don't continuously decrease because all object are also absorbing radiant energy.
18. Surrounding temperature determines whether an object is a net emitter or absorber.
19. A black pot both warms faster (and cools faster) than a silver pot.
20. A good absorber cannot at the same time be a good reflector because absorption and reflection are opposite processes.
21. The pupil appears black because light that enters the eye usually doesn't exit. With flash cameras, however, some of it does.
22. Temperature will drop when radiation exceeds absorption.
23. Poor conductivity means little heat from the ground and the object can cool by radiation to temperatures below that of the surrounding air temperature.
24. By Newton's law of cooling, the hot poker in the cold room radiates more due to the greater temperature difference between the poker and the room.
25. Yes, Newton's law of cooling also applies to warming.
26. With no greenhouse effect Earth would be a very cold place, with an average temperature about -18°C.
27. Glass allows high-frequency visible-light radiant energy in, but prevents low-frequency infrared re-radiated energy out. Likewise for the atmosphere acting as a one-way valve.
28. Weather is the state of the atmosphere at a particular time and place. Climate is the weather pattern over broader regions and longer times.
29. The Sun pours 1400 J of radiant energy per second per meter squared at the top of the atmosphere.
30. Heat transfer by conduction, convection, and radiation is inhibited in a Thermos bottle.

Think and Do

31. This activity nicely shows that metal is a good conductor of heat. Paper in a flame by itself easily reaches ignition temperature and catches fire. But this ignition temperature isn't reached when the paper is wrapped around a thick metal bar that absorbs energy from the flame, which then isn't absorbed by the paper.

32. The heat you feel is radiant energy, which passes through the glass, without heating the glass.
33. Tell Grandma how clouds re-radiate terrestrial energy back to Earth's surface. Examples abound about all objects both emitting and absorbing energy.

Plug and Chug

34. $Q = cm\Delta T$ = (1 cal/g·°C)(50 g)(100°C – 0°C) = 5,000 cal.
35. $Q = cm\Delta T$ = (1 cal/g·°C)(20 g)(90°C – 30°C) = 1,200 cal.

Think and Solve

36. From $Q = cm\Delta T$, $Q/m = c\Delta T$ = (800 J/kg·C°)(500°C) = 400,000 J/kg. (Q/m is the energy per kg, which is the same whatever the mass.) The time required is about (400,000J/kg)/(0.03 J/kg·yr) = 13 million years. Small wonder it remains hot down there!

37. The coffee decreases 25°C in temperature in eight hours. Newton's law of cooling tells us that its rate of cooling is proportional to the temperature difference. So when the temperature difference is half as great, the rate of cooling will be half as great. Hence, the coffee will lose 12.5 degrees in another eight hours, half as much as in the first eight hours, cooling from 50°C to 37.5°C.

38. Because of the 20-percent conversion efficiency, each square meter of collector will supply 40 watts of electric power on average. So to meet the 3 kW requirement you will need (3000 W)/(40 W/m^2) = 75 m^2 of collector area. This is the area of a square about 9 m or 28 ft on a side. It would fit in a typical yard, but is a little larger than a typical roof.

39. (a) *Q* gained by water = *Q* lost by nails, so $(cm\Delta T)_{water} = (cm\Delta T)_{nails}$.
(1.0 g°C)(100g)(T - 20°C) = (0.11 cal/g°C)(100 g)(40° - T), where T = 22°C.
(b) Although the masses are the same, the specific heats are widely apart, iron being very low and water incredibly high. It takes as much heat as the iron can release to raise water by about 2°C.

Think and Explain

40. The metal doorknob conducts heat better than wood.

41. Feathers (and the air they trap) are good insulators and thus conduct body heat very slowly to the surroundings.

42. No, the coat is not a source of heat, but merely keeps the thermal energy of the wearer from leaving rapidly.

43. Air at 70°F feels comfortable principally because it is a poor conductor. Our warmer skin is slow to transfer heat to the air. Water, however, is a better conductor of heat than air, so our warmer bodies in water more readily transfer heat to the water.

44. When the temperatures of the blocks are the same as the temperature of your hand, then no heat transfer occurs. Heat will flow between your hand and something being touched only if there is a temperature difference between them.

45. Energy "flows" from higher to lower temperature, from your hand to the ice. It is the energy, heat, flowing from your hand that produces the sensation of coolness. There is no flow from cold to hot; only from hot to cold.

46. Air is an excellent insulator. The reason that fiberglass is a good insulator is principally because of the vast amount of air spaces trapped in it.

47. In touching the tongue to very cold metal, enough heat can be quickly conducted away from the tongue to bring the saliva to sub-zero temperature where it freezes, locking the tongue to the metal. In the case of relatively nonconducting wood, much less heat is conducted from the tongue and freezing does not take place fast enough for sudden sticking to occur.

48. Heat from the relatively warm ground is conducted by the gravestone to melt the snow in contact with the gravestone. Likewise for trees or any materials that are better conductors of heat than snow, and that extend into the ground.

49. There is more air space in mittens than in gloves, which makes for warmer hands. Also, the fingers in mittens are next to one another which also keeps hands warmer.

50. Wood is a poor conductor whatever the temperature, so you can safely grab a pan by its wooden handle for a short time. Very little heat will be conducted to your hand. Touching the iron part of the pan is another story, for then heat is readily conducted to your hand. Ouch again!

51. The conductivity of wood is relatively low whatever the temperature—even in the stage of red-hot coals. You can safely walk barefoot across red hot wooden coals if you step quickly (like removing the wooden-handled pan with bare hands quickly from the hot oven in the previous exercise) because very little heat is conducted to your feet. Because of the poor conductivity of the coals, energy from within the coals does not readily replace the energy that transfers to your feet. This is evident in the diminished redness of the coal after your foot has left it. Stepping on red-hot *iron* coals, however, is a different story. That would be a resounding ouch!

52. Yes in both cases, as long as one has a higher temperature than the other. Differences in *temperature*, not internal energy, dictates heat flow.

53. The temperature will be in between because one decreases in temperature and the other increases in temperature.

54. It is thermal energy that flows—heat. It is therefore correct to say that thermal energy flows between the objects.

55. It is correct to say that the increase in *thermal energy* of one object equals the decrease in *thermal energy* of the other—not temperature. The statement is correct when the hot and warm objects are the same material and same mass.

56. Hydrogen molecules will be the faster moving when mixed with oxygen molecules. They will have the same temperature, which means they will have the same average kinetic energy. Recall that KE = 1/2 mv^2. Since the mass of hydrogen is considerably less than oxygen, the speed must correspondingly be greater.

57. As in the explanation of the previous exercise, the molecules of gas with the lesser mass will have the higher average speeds. A look at the periodic table will show that argon (A = 18) has less massive atoms than krypton (A = 36). The faster atoms are those of argon. This is the case whether or not the gases are in separate containers.

58. Molecules of gas with greater mass have a smaller average speed. So molecules containing heavier U-238 are slower on the average. This favors the diffusion of the faster gas containing U-235 through a porous membrane (which is how U-235 was separated from U-238 by scientists in the 1940s).

59. As with the previous question, the faster molecules with U-235 will diffuse faster than the slower molecules with heavier U-238.

60. More molecules are in the cooler room. The greater number of slower-moving molecules there produce air pressure at the door equal to the fewer number of faster-moving molecules in the warmer room.

61. The smoke, like hot air, is less dense than the surroundings and is buoyed upward. It cools with contact with the surrounding air and becomes more dense. When its density matches that of the surrounding air, its buoyancy and weight balance and rising ceases.

62. If ice cubes were at the bottom they wouldn't be in contact with the warmest part of the tea at the surface, so cooling would be less. Ice cubes are preferable at the surface to decrease the temperature of the warmer part of the tea.

63. Both the molecule and the baseball are under the influence of gravity, and both will accelerate downward at *g*. When other molecules impede downward fall, then the free-fall acceleration *g* isn't maintained.

64. Faster-moving (warm air) molecules migrate upward through the "open window" in the atmosphere, producing upward convection.

65. Because of the high specific heat of water, sunshine warms water much less than it warms land. As a result, air is warmed over the land and rises. Cooler air from above the cool water takes its place and convection currents are formed. If land and water were heated equally by the Sun, such convection currents (and the winds they produce) wouldn't be established.

66. When we warm a volume of air, we add energy to it. When we expand a volume of air, we normally take energy out of it (because the expanding air does work on its surroundings). So the conditions are quite different and the results will be different. Expanding a volume of air actually lowers its temperature.

67. No. However ceiling fans can create a "wind chill" effect that can make you feel up to five degrees cooler. Ceiling fans do not reduce the temperature in the room, but merely circulate air, making you feel cooler.

68.In winter you want warm air near the floor, so the fan should push warmer ceiling air downward. In summer you want cooler air near the floor, so the fan should pull air upward.

69.The mixture expands when it is ejected from the nozzle, and therefore cools. At the freezing temperature of 0°C, ice forms.

70. Radiation requires no medium for transfer.

71. A good emitter, by virtue of molecular-or-whatever design, is also a good absorber. A good absorber appears black because radiation that impinges upon it is absorbed; just the opposite of reflection.

72. Human eyes are insensitive to the infrared radiated by objects at average temperatures.

73. If good absorbers were not also good emitters, then thermal equilibrium would not be possible. If a good absorber only absorbed, then its temperature would climb above that of poorer absorbers in the vicinity. And if poor absorbers were good emitters, their temperatures would fall below that of better absorbers.

74.A good reflector is a poor radiator of heat, and a poor reflector is a good radiator of heat.

75. The energy given off by rock at the Earth's surface transfers to the surroundings practically as fast as it is generated. Hence there isn't the buildup of energy that occurs in the Earth's interior.

76. Heat radiates into the clear night air and the temperature of the car goes down. Normally, heat is conducted to the car by the relatively warmer ground, but the rubber tires prevent the conduction of heat from the ground. So heat radiated away is not easily replaced and the car cools to temperatures below that of the surroundings. In this way frost can form on a below-freezing car in the above-freezing environment.

77. Under open skies, the ground radiates upward but the sky radiates almost nothing back down. Under the benches, downward radiation of the benches decreases the net radiation from the ground, resulting in warmer ground and, likely, no frost.

78. When it is desirable to reduce the radiation that comes into a greenhouse, whitewash is applied to the glass to simply reflect much of the incoming radiation. Energy reflected is energy not absorbed.

79. For maximum warmth, wear the plastic coat on the outside and utilize the greenhouse effect.

80. If the upper atmosphere permitted the escape of more terrestrial radiation than it does presently, more energy would escape and the Earth's climate would be cooler.

81. Because warm air rises, there's a higher temperature at the ceiling than at the walls. With a greater difference in inside and outside temperatures, thicker insulation is needed to slow the transfer of heat.

82. Open-ended.

Think and Discuss

83. Copper and aluminum are better conductors than stainless steel, and therefore more quickly establish a uniform temperature over the bottom of the pan and transfer heat to the cookware's interior.

84. The main reason for serving potatoes wrapped in aluminum foil is to increase the time that the potatoes remain hot after being removed from the oven. Heat transfer by radiation is minimized as radiation from the potatoes is internally reflected, and heat transfer by convection is minimized as circulating air cannot make contact with the shielded potatoes. The foil also serves to retain moisture.

85.The snow and ice of the igloo is a better insulator than wood. You would be warmer in the igloo than the wooden shack.

86.Agree, for your friend is correct. The gases will have the same temperature, which is to say they'll have the same average kinetic energy per molecule.

87. Disagree, for although the mixture has the same temperature, which is to say, the same KE per molecule, the lighter hydrogen molecules have more speed than heavier nitrogen for the same KE.

88. Air molecules in your room have the same *average* kinetic energy, but not the same average speed. Air is made up of molecules of different *mass*—some nitrogen, some oxygen, and a small percentage of other gases. So even though they have the same average kinetic energy, they won't have the same average speed. The lighter molecules will have average speeds greater than the heavier molecules.

89. They ride in "thermals," updrafts of air.

90. At the same temperature, molecules of helium, nitrogen, and oxygen have the same average kinetic energy. But helium, because of its smaller mass, has greater average speed. So some helium atoms, high in the atmosphere, will be moving faster than escape speed from the Earth and will be lost to space. Through random collisions, every helium atom will eventually surpass escape speed.

91. Kelvins and Celsius degrees are the same size, and although ratios of these two scales will produce very different results, *differences* in kelvins and *differences* in Celsius degrees will be the same. Since Newton's law of cooling involves temperature differences, either scale may be used.

92. Put the cream in right away for at least three reasons. Since black coffee radiates more heat than white coffee, make it whiter right away so it won't radiate and cool so quickly while you are waiting. Also, by Newton's law of cooling, the higher the temperature of the coffee above the surroundings, the greater will be the rate of cooling—so again add cream right away and lower the temperature to that of a reduced cooling rate, rather than allowing it to cool fast and then bring the temperature down still further by adding the cream later. Also—by adding the cream, you increase the total amount of liquid, which for the same surface area, cools more slowly.

93. Turn your heater off altogether and save fuel. When it is cold outside, your house is constantly losing heat. How much is lost depends on the insulation and the difference in inside and outside temperature (Newton's law of cooling). Keeping ΔT high consumes more fuel. To consume less fuel, keep ΔT low and turn your heater off altogether. Will more fuel be required to reheat the house when you return than would have been required to keep it warm while you were away? Not at all. When you return, you are replacing heat lost by the house at an average temperature below the normal setting, but if you had left the heater on, it would have supplied more heat, enough to make up for heat lost by the house at its normal, higher temperature setting. (Perhaps your instructor will demonstrate this with the analogy of leaking water buckets.)

94. Turn the air conditioner off altogether to keep ΔT small, as in the preceding answer. Heat leaks at a greater rate into a cold house than into a not-so-cold house. The greater the rate at which heat leaks into the house, the greater the amount of fuel consumed by the air conditioner.

95. If the Earth's temperature increases, its rate of radiating will increase. And if much of this extra terrestrial radiation is blocked, and the temperature of the Earth increases more, then its rate of radiating simply increases further. A new and higher equilibrium temperature is established.

96. The photovoltaic cell converts solar energy into electrical energy.

97. Assuming 1.0 kW of solar energy over 1 m^2 at Earth's surface, the question is how many square feet are in one square meter, which is a bit more than 10 square feet.
1.0 kW = 1000 W. So 1000 W/10 = 100 W, as with a 100-W bulb.

98. Every mathematical equation illustrates that you can't only change one thing. Change a term in the left side of any equation, and a corresponding change occurs in the right side. This is a lesson nature teaches us.

99. In the Industrial Era coal was burned to produce the energy that created the industrial revolution. Plastics and many modern materials are made from fossil fuels, which in the long term, should prove to be much more valuable than turning coal and oil to heat and smoke.

100. Humans consume energy. More humans consume more energy. Consumption relates to energy waste and pollution. Simply put, more humans, more pollution.