17 Change of Phase

That's nephew John Suchocki walking barefoot on hot coals in the chapter opening photo 1. John is my co-author, with my daughter Leslie, on *Conceptual Physical Science* textbooks. In his uncle's footsteps, he's written *Conceptual Chemistry*, Fifth Edition, published by Benjamin Cummings, a beautiful book. In photo 2 lab manual author Dean Baird demonstrates regelation, and quite happily the chapter opens with his personal profile. Photo 3 is Ron Hipschman, who has been a physicist at the Exploratorium since its inception back in the Frank Oppenheimer days. Three cheers for Ron! The doggies belong to family friend Tammy Tunison.

The profile of this chapter is lab-manual author, Dean Baird.

Material from this chapter is not prerequisite to the chapters that follow. As with Chapter 16, the emphasis is on bodies of water and the atmosphere.

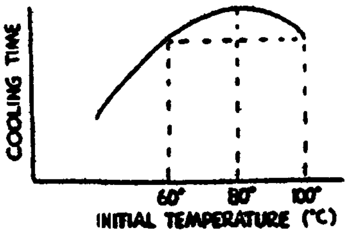
Some textbooks speak of change of *state*. Here we use change of *phase*. Either is acceptable, but change of phase has the benefit of not being confused with energy states.

Change of phase is wonderfully employed in crystal heat pouches of recent years. Latent heat is released when crystallization of sodium acetate occurs. Repeatable. (Arbor Scientific, CRYSTALHEAT P3-1015.)

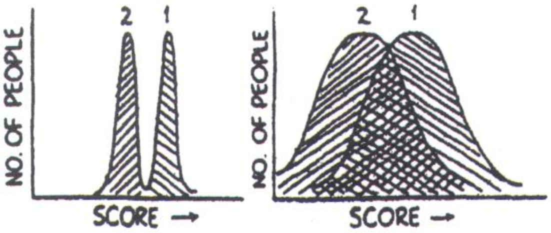
Note that the units calories are primary in this chapter, particularly with heats of fusion and vaporization of water. Values for heats of fusion and vaporization, 80 and 540 calories/g are easier figures than SI units 334.88 kJ/kg and 2.26 MJ/kg respectively. Both units are used.

Thanks to physics professor David Willey for his firewalking photo, Figure 17.21. Are there still people out there who attribute firewalking to mind over matter rather than straight-forward physics?

The considerable amount of energy that goes into vaporization explains why under some conditions hot water will freeze faster than warm water. This occurs for water hotter than about 80°C, and is evident when the surface area that cools by rapid evaporation is large compared to the amount of water involved—like washing a car with hot water on a cold winter day, or flooding a skating rink to melt and smooth out the rough spots and freeze quickly. The 540 calories per gram of water that evaporates is substantial. This is treated in Practice Page 77. Will boiling water freeze before cold water? No. But boiling water will freeze before water warmer than 60°C. A plot showing freezing times (thanx to Jearl Walker) is shown at the right. Surprisingly, water at 80°C takes longer to freeze than water at 99°C. But for water temperatures less than 80°C, common sense prevails.



In a conversation with Richard Feynman, just 3 months before he died, we discussed the rapid freezing of hot water. He speculated that the lesser amount of trapped air in hot water may contribute to its quick freezing.



If you wish to introduce the idea of distribution curves in your course, this is a good place to do it. Treat the cooling produced by evaporation with plots of relative numbers of molecules in a liquid versus their speeds, and show how the distribution shifts as the faster-moving molecules evaporate. You may wish to point to the bell-shape distribution curves that represent the distributions of so many things, from molecular speeds to examination scores to people’s IQ scores. Regrettably, many people tend to regard such distributions not as bell-shaped, but as spikes. This makes a difference in attitudes. For example, suppose you compare the grade distributions for two sections of your course, Group 1 and Group 2, and that the average score for Group 1 is somewhat greater than that for Group 2. For whatever reason, Group 1 outperforms Group 2. With this information can we make any judgment about individuals from either group? One who looks at these distributions as spiked shaped behaves as if he can—he’ll say (or not say but think) that individuals from Group 1 are “better” than particular individuals from Group 2. On the other hand, one who thinks in terms of the broad shape of the bell-shaped distribution will not make any assumptions about such individuals. He is well aware of the region of overlap in the two distribution curves. His attitude toward individuals from either group is unbiased by unwarranted prejudice. Hence the difference between narrow-mindedness and broad-mindedness!

The explanation of ice melting under pressure with regard to ice-skating has been controversial for several years now. Conceptually, it is easy to visualize the pressure of the ice blade crushing the open structures of ice crystals, accounting for the layer of water that results on the surface, which provides the slipperiness. Investigation indicates that water molecules on the surface of ice vibrate faster than their temperatures suggest, forming a quasi liquid layer even at temperatures well below freezing. So this mobile surface may better explain how skating and skiing are possible.

The drinking bird demo, Figure 17.4, is available from Arbor Scientific (P3-5001), or with a discovery pack of more gas-laws goodies (P1-2070). A “giant” 25-cm tall drinking bird (P3-5014).

Are you using the check-your-neighbor technique in your lectures? As emphasized already, it makes a substantial positive difference.

Practicing Physics Book:
- Ice, Water, and Steam
- Our Earth’s Hot Interior
- Evaporation

Problem Solving Book:
Ample problems to complement this chapter

Laboratory Manual:
- Cooling While Boiling *Atmospheric Pressure and Boiling Point* (Demonstration)
- Heating While Freezing *Heat of Fusion* (Experiment)

Next-Time Questions:
- Steam to Melt Ice
- Evaporating Hot Water
- Evaporation
- Boiling
- Ice Melt

Hewitt-Drew-It! Screencasts: •*Evaporation and Condensation* •*Crunching Can and Dipping Bird* •*Energy Changes of Phase* •*More on Phase Changes*

SUGGESTED LECTURE PRESENTATION

Evaporation

Begin by citing the familiar case of leaving the water when bathing and feeling chilly in the air, especially when it is windy. Explain the cooling of a liquid from an atomic point of view, and reinforce the idea of temperature being a measure of the average molecular kinetic energy, and acknowledge molecules that move faster and slower than the average.

> CHECK QUESTION: Why does cooling occur in the water of a leaky canvas water bag? [Water seeps through the canvas. More faster-moving molecules leak and vaporize, leaving less energy per molecule behind.]

> CHECK QUESTION: Cite at least two ways to cool a hot cup of coffee. [You can increase evaporation by blowing on it or pouring it into the saucer to increase the evaporating area. You can cool it by conduction by putting silverware in it, which absorbs heat and provides a radiating antenna.]

Make a sketch a bell-shaped distribution curve to represent the wide array of molecular speeds in a container of water. The peak of the curve represents the speeds that correspond to the temperature of the water. (It is not important to distinguish here between the mean speed, the rms speed, and the most probable speeds.) Stress the many lower and higher speeds to the left and right of the peak of your curve at any moment in the water. Which molecules evaporate? The fast ones, which you clip from the right hand tail of your curve. What is the result? A shift toward the left of the peak of the curve—a lowering of temperature. (Actually, this approach is highly exaggerated, for the molecules that do penetrate the surface and escape into the air have energies that correspond to 3400K! See my article on page 492 of *The Physics Teacher*, back in October, 1981.)

The relatively strong bond between water molecules (hydrogen bonding) prevents more evaporation than presently occurs. It also enhances condensation.

Condensation

If evaporation is a cooling process, what kind of process would the opposite of evaporation be? This is condensation, which is a warming process.

> CHECK QUESTION: Why is it that many people after taking a shower will begin drying in the shower stall before getting outside? [While still in the shower region, appreciable condensation offsets the cooling by evaporation.]

Make the point that a change of phase from liquid to gas or vice versa is not merely one or the other. Condensation occurs while evaporation occurs and vice versa. The net effect is usually what is spoken about. If you haven’t shown the collapsing can demo in your atmospheric pressure lecture, and for some reason you’re not treating Chapter 18, now is a good time.

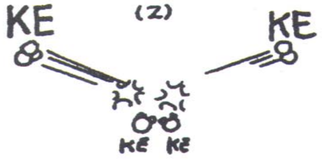
> DEMONSTRATION (as treated in Chapter 18): Heat some aluminum soda pop cans on a burner, empty except for a small amount of water that is brought to a boil to make steam. With a pot holder or tongs, pick up a can and quickly invert it into a basin of water. Crunch! The atmospheric pressure immediately crushes the can with a resounding WHOP! Very impressive! Do this first by inverting cans into a cold basin of water. It is evident that condensation of the steam and vapor on the inside takes place, pressure is correspondingly reduced, and the atmospheric pressure on the outside crunches the can. Then repeat but this time invert cans into a basin of very hot water, just short of the boiling temperature. Crunch again, but less forceful than before. Steam molecules stick to the water surface, hot or cool, like flies sticking to fly paper (and like the “kissing molecules” of Figure 17.8). Then repeat, but this time invert cans into *boiling* water. No crunch because boiling is supplying molecules as others condense—a stand off. Lead your class into the explanation wherein the *net* effect is no change, as condensation of steam is met with just as much vaporization from the boiling water. The punch line of this demo is shown in the box

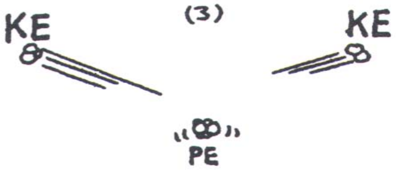
THERMODYNAMICS DRAMATIZED on page 346 in the next chapter—the reason for condensation in a steam turbine—to reduce pressure on the backside of the turbine blades.

Condensation in the Atmosphere

An interesting way to present the condensation of water vapor to droplets is the following: Ask why a glass containing an iced drink becomes wet on the outside, and why a ring of moisture is left on the table. I inject a bit of humor here and state that the reason is... and then write the number 17.8 on the board. Then ask why the walls of the classroom would become wet if the temperature of the room were suddenly reduced. State that the answer is...then underline 17.8. Ask why dew forms on the morning grass, and state the answer is ... another underline for 17.8. Ask why fog forms, and how the clouds form, and back to your 17.8. By now some of your class is wondering about the significance of 17.8. Announce you're discussing Figure 17.8, and with class attention and interest continue discussion of the formation of fog and clouds (and even rain, hail, and snow). [Snow crystallizes from vapor; hail is rain that freezes when tossed upward, often repeatedly, by strong updrafts.]

The mechanics of energy release to the surrounding air by water vapor when it condenses can be understood with billiard-ball physics. H_2O molecules simply give most of their KE to the air during their last collision before condensation. The details are shown in the three sketches below.





Consider two pairs of molecules, say with equal KEs before collision (Sketch 1). After collision, individual KEs may be quite unequal, for molecules that transfer much of their KE to others are left with corresponding less KE of their own (Sketch 2). So far, there is no change in the air's total KE score. But if the slower molecules happen to be H_2O, they are candidates for condensation if their next collisions are with other H_2Os that have similarly just given most of their KE to neighboring molecules (Sketch 3). Upon condensation of the slow-moving H_2Os, molecules left in the air have an increase in average KE. Voila! *H_2O molecules transfer KE to the surrounding air during their last collision while in the gaseous phase*—the collision that immediately precedes condensation. The energy gained by the air is the well-known heat of vaporization—about 540 calories per gram of condensed H_2O for an ambient temperature of 100°C. It's greater for lower temperatures (molecules bopped to high speeds in a low-speed environment gain more energy than molecules bopped to the same high speeds in higher-speed environments). So all things being equal, a rainy day really is warmer than a cloudy day.

Condensation is enhanced by the presence of ions, dust, or tiny particles that act as the nuclei of droplets. London became much foggier when coal burning provided more particles in the air to initiate condensation. This occurred big time in Beijing, China, in 2013.

Cloud formation is a "4-C process": 1. Convection upward and expansion, 2. Cooling due to expansion, 3. Condensation due to cooling, and 4. Cloud formation.

Boiling

Discuss boiling and the roles of adding heat and pressure in the boiling process. A tactic I use throughout my teaching is to ask the class members to pretend they are having a one to one conversation with a friend about the ideas of physics. Suppose a friend is skeptical about the idea of boiling being a cooling process. I tell my class just what to say to convince the friend of what is going on. I tell them to first point out the distinction between heating and boiling. If the friend knows that the temperature of boiling water remains at 100°C regardless of the amount of heat applied, point out that this is so because the water is cooling by boiling as fast as it is being warmed by heating. Then if this still is not convincing, ask the friend to hold her hands above a pot of boiling water—in the steam. She knows she'll be burned. But burned by what? By the steam. And where did the steam get its energy? From the boiling water; so energy is leaving the water—that's what we mean by cooling! Bring in the role of pressure on boiling, and illustrate this with the pressure cooker.

> CHECK QUESTIONS: In bringing water to a boil in the high mountains, is the time required to bring the water to a boil longer or shorter than at sea level? Is the time required for cooking longer or shorter? (Preface this second question with the statement that you are posing a different question, for any confusion about this is most likely due to failing to distinguish between the two questions.)

> DEMONSTRATION: Evacuate air from a flask of room-temperature water, enough so that the water in the flask will boil from the heat of the students' hands as it is passed around the classroom. (Take care that the flask is strong enough so that it doesn't implode!)

Geyser: Explain how a geyser, Figure 17.12, is like a pressure cooker (or the old-time coffee percolators).

Boiling and Freezing at the Same Time
This must be seen to be appreciated!

> DEMONSTRATION: The triple-point demonstration, Figure 17.14. [The apparatus for freezing water by air evacuation at the Exploratorium in San Francisco is briefly shown in the video on Evaporation in the *Conceptual Physics Alive!* series and in the chapter photo opener of Ron Hipschman with the "Water Freezer" Exploratorium exhibit.]

Melting and Freezing

> DEMONSTRATION: Regelation of an ice cube with a copper wire, Figure 17.16. Dean Baird demonstrated this in the chapter opener photo. (The wire must be a good heat conductor for this to work, as discussed in the footnote on page 328.)

Energy and Changes of Phase
Ask if it is possible to heat a substance without raising its temperature, and why a steam burn is more damaging than a burn from boiling water at the same temperature. In answering these, discuss the change-of-phase graph of Figure 17.17, and then relate it to Figure 17.15. After citing examples of changes of phase where energy is absorbed, cite examples where energy is released—like raining and snowing. People sometimes say that it is too cold to snow. Explain that this statement arises from the fact that when it is snowing, the air temperature is higher than would otherwise be the case—that whenever it *is* snowing the air is relatively warm, so it is really never too cold to snow. Ask about cooling a room by leaving the refrigerator door open, and compare it to putting an air conditioner in the middle of a room instead of mounting it in a window. Ask what the result would be of mounting an air conditioner backwards in a window.

Air Conditioning
In view of the ozone-destroying chemicals used as refrigerants, cite present efforts you are acquainted with in developing alternative systems. Freon is now replaced by a refrigerant called HFC-134a. Alternative air conditioning systems will likely be in the forefront of news on new technologies. They're needed.

Chicanery
In recent years scams have been popular that extract a fee to learn to walk barefoot on red-hot coals of wood. The explanation given was a "mind over matter" one. As it so happens, the feat is better explained by simple physics. When the surfaces of coals with a low heat conductivity transfer heat to a foot that steps on them, sufficient time is required before appreciable internal energy from the inside a coal reheats the surface. So low heat conductivity is the central part of the feat, not mind over matter. All the mind over matter in the world wouldn't protect a person who walks on red-hot coals of a good conductor, like pieces of metal.

Answers and Solutions for Chapter 17

Reading Check Questions

1. The four common phases of matter are solids, liquids, gases, and plasmas.
2. In a liquid are a wide variety of molecular speeds.
3. Evaporation is a change of phase from liquid to gaseous.
4. Evaporation is called a cooling process because the remaining liquid has given some of its KE to the gas and has cooled.
5. Sublimation is the change of phase from solid to gas directly.
6. They are opposite processes, evaporation from liquid to gas and condensation from gas to liquid.
7. Steam contains more energy than boiling water of the same temperature.
8. On a muggy day you experience condensation from the air, which cancels the cooling due to evaporation.
9. Humidity is a measure of how much water vapor is in the air; relative humidity is the ratio of how much water is in the air to the largest amount of water vapor the air can hold at a given temperature.
10. Slower-moving molecules stick upon collision and therefore condense (Figure 17.8).
11. As the air rises, it cools and condenses to form clouds.
12. Altitude distinguishes fog from a cloud.
13. When evaporation occurs beneath the surface of a liquid, it is said to be boiling.
14. Increased atmospheric pressure increases the boiling point of water.
15. Higher temperature, not boiling, cooks food faster.
16. Water at the bottom of a geyser is under pressure and won’t boil at 100°C.
17. When water above gushes out, pressure at the bottom is reduced, and then water boils.
18. More energy input means more energy output as boiling (and therefore cooling) occurs. Hence boiling water stays at its boiling temperature.
19. The boiling point of water is reduced when pressure of air above is reduced.
20. Evidence that water can boil at 0°C occurs when water freezes while it’s boiling (as Ron Hipschman demonstrates in the photo opener.)
21. Increasing temperature means increased motion, which means more chance of molecule separation.
22. Decreasing temperature means decreased motion, which means more chance of molecules sticking together.
23. Foreign ions decrease the number of water molecules at the interface between ice and water where freezing occurs.
24. The open hexagonal structure of ice can be crushed with sufficient pressure.
25. The block doesn’t separate into two pieces because water above the wire refreezes when pressure on it is reduced.
26. A liquid absorbs energy when it changes to a gas.
27. A liquid releases energy when it changes to a solid.
28. Heat is discharged by condensation.
29. One calorie; 80 calories; 540 calories.
30. One reason feet don’t burn involves low conductivity of hot coals. The other reason is energy that goes to the water on the feet does not go to the feet directly.

Think and Do

31. A geyser and a coffee percolator work on the same principle.

32. This activity (Figure 16.8 in the previous chapter) demonstrates that steam is the invisible part of the vapor stream from a spout. A candle flame in the condensed part extinguishes.

33. The rainfall seen resembles actual rain, in that condensation of vapor leads to drops of water. It differs in that natural rain is the result of cooling in clouds of vapor, rather than by condensation on a chilled surface.

34. The salted water has a higher boiling point.

35. When you do this, the ice will end up intact!

36. Clarify what is meant by saying boiling is a cooling process.

Think and Solve

37.(a) 1 kg 0°C ice to 0°C water requires 80 kilocalories.

(b) 1 kg 0°C water to 100°C water requires 100 kilocalories.
(c) 1 kg 100°C water to 100°C steam requires 540 kilocalories.
(d) 1 kg 0°C ice to 100°C steam requires (80 + 100 + 540) = 720 kilocalories
or 720,000 calories.

38. From -273°C "ice" to 0°C ice requires (273)(0.5) = 140 calories.
From 0°C ice to 0°C water requires 80 calories.
From 0°C water to 100°C water requires 100 calories.
The total is 320 calories.
Boiling this water at 100°C takes 540 calories, considerably more energy than it took to bring the water all the way from absolute zero to the boiling point! (In fact, at very low temperature, the specific heat capacity of ice is less than 0.5 cal/g°C, so the true difference is even greater than calculated here.)

39. First, find the number of calories that 10 g of 100°C steam will give in changing to 10 g of 0°C water.
10 g of steam changing to 10 g of boiling water at 100°C releases 5400 calories.
10 g of 100°C water cooling to 0°C releases 1000 calories.
So 6400 calories are available for melting ice.

$$\frac{6400 \text{ cal}}{80 \text{ cal/g}} = 80 \text{ grams of ice.}$$

40. The final temperature of the water will be the same as that of the ice, **0°C**. The quantity of heat given to the ice by the water is $Q = cm\Delta T$ = (1 cal/g°C)(50 g)(80°C) = 4000 cal. This heat melts ice. How much? From $Q = mL$, $m = Q/L$ = (4000 cal)/(80 cal/g) = 50 grams. So water at 80°C will melt an equal mass of ice at 0°C.

41. The quantity of heat lost by the iron is $Q = cm\Delta T$ = (0.11 cal/g°C)(50 g)(80°C) = 440 cal. The iron will lose a quantity of heat to the ice $Q = mL$. The mass of ice melted will therefore be $m = Q/L$ = (440 cal)/(80 cal/g) = 5.5 grams. (The lower specific of heat of iron shows itself compared with the result of the previous problem.)

42. $mgh = mL$, so $gh = L$ and $h = L/g$.
h = (334000 J/kg)/(9.8 m/s^2) = 34000 m = 34 km.
Note that the mass cancels and that the unit J/kg is the same as the unit m^2/s^2. So in the ideal case of no energy losses along the way, any piece of ice that freely falls 34 km will completely melt upon impact.

43. PE = Q; $0.5mgh = cm\Delta T$
$\Delta T = 0.5mgh/cm = 0.5gh/c$ = (0.5)(9.8 m/s^2)(100 m)/(450 J/kg°C) = 1.1°C. Mass cancels out.

44. Note that the heat of vaporization of ethyl alcohol (200 cal/g) is 2.5 times more than the heat of fusion of water (80 cal/g), so in a change of phase for both, 2.5 times as much ice will change phase; 2.5 × 2 kg = 5 kg. Or via formula, the refrigerant would draw away $Q = mL$ = (2000 g)(200 cal/g) = 4×10^5 calories. The mass of ice formed is then (4×10^5 cal)/(80 cal/g) = 5000 g or 5 kg.

Think and Rank

45. A, B, C.
46. C, B, A.

Think and Explain

47. The water evaporates rapidly in the dry air, gaining its energy from your skin, which is cooled.

48. When sweat evaporates it carries energy from the skin, producing cooling.

49. When you blow over the top of a bowl of hot soup, you increase net evaporation and its cooling effect by removing the warm vapor that tends to condense and reduce net evaporation.

50. The temperature of the water lowers.

51. The energy that keeps the dunking duck in operation comes from the Sun, lamps, or whatever is heating the lower chamber where evaporation is taking place. To see this, simply direct heat energy to the lower chamber of the duck and you'll see an increase in the number of times per minute the duck dunks.

52. If the perfume doesn't evaporate it will produce no odor. The odor of a substance is evidence for its evaporation. Don't invest in this invention!

53. A fan does not cool the room, but instead promotes evaporation of perspiration, which cools the body.

54. The wet cloth cools by evaporation. As evaporation progresses, the temperature of the water in the cloth drops, and cools the bottle to a temperature below that of the bucket of water.

55. The body maintains its temperature at a normal 37°C by the process of evaporation. When the body tends to overheat, perspiration occurs, which cools the body if the perspiration is allowed to evaporate. (Interestingly enough, if you're immersed in hot water, perspiration occurs profusely, but evaporation and cooling do not follow—that's why it is inadvisable to stay too long in a hot bath.)

56. Visibility of the windows is impaired if there is any condensation of water between the panes of glass. Hence the gas between the panes should contain no water vapor.

57. Air above the freezing temperature is chilled in the vicinity of an iceberg and condensation of the water vapor in the air results in fog.

58. Aside from the connotation of kissing molecules and parking on a cool night, the warm moist air generated in the car's interior meets the cold glass and a lowering of molecular speed results in condensation of water on the inside of the windows.

59. On a day where the outside of the windows is warmer than the inside, condensation will occur on the outside of the windows. You can also see this on the windshield of your car when you direct the air conditioner against the inside of the glass.

60. A temperature gradient normally exists in a room, with cooler air near the bottom. Hence frost forms on the colder part of the window, the bottom.

61. Air swept upward expands in regions of less atmospheric pressure. The expansion is accompanied by cooling, which means molecules are moving at speeds low enough for coalescing upon collisions; hence the moisture that is the cloud.

62. Clouds tend to form over islands because land has a lower specific heat capacity than water, so the land is warmed faster than the surrounding water. This causes updrafts above the warmed land; the rising air laden with H_2O expands and cools, allowing the H_2O molecules to coalesce (Figure 17.8).

63. Enormous thermal energy is released as molecular potential energy is transformed to molecular kinetic energy in condensation. (Freezing of the droplets to form ice adds even more thermal energy.)

64. When water is boiling, it is being cooled by the boiling process as fast as it is being heated by the stove. Hence its temperature remains the same—100°C.

65. As the bubbles rise, less pressure is exerted on them.

66. Decreased pressure lessens the squeezing of molecules, which favors their tendency to separate and form vapor.

67. When the jar reaches the boiling temperature, further heat does not enter it because it is in thermal equilibrium with the surrounding 100°C water. This is the principle of the "double boiler."

68. The hot water is below the boiling point for the very high pressure there, somewhat like the higher boiling point of water in a pressure cooker.

69. No. Food is cooked by the high temperature it is subjected to, not by the bubbling of the surrounding water. For example, put room-temperature water in a vacuum and it will boil. But an egg in this boiling water won't cook at all!

70. As in the answer to the previous exercise, high temperature and the resulting internal energy given to the food are responsible for cooking—if the water boils at a low temperature (presumably under reduced pressure), the food isn't hot enough to cook.

71. Moisture in the cloth will convert to steam and burn you.

72. Both heat and pressure are involved in boiling. Reduction of pressure only can produce boiling (see Figure 17.14).

73. The ice is indeed cold. Why cold? Because rapid evaporation of the water cooled the water to the freezing point.

74. The air in the flask is very low in pressure, so that the heat from your hand will produce boiling at this reduced pressure. (Your instructor will want to be sure that the flask is strong enough to resist implosion before handing it to you!)

75. Cooking time will be no different for vigorously boiling water and gently boiling water, for both have the same temperature. The reason spaghetti is cooked in vigorously boiling water is simply to ensure the spaghetti doesn't stick to itself and the pan. For fuel economy, simply stir your spaghetti in gently boiling water.

76. The lid on the pot traps heat that quickens boiling; the lid also slightly increases pressure on the boiling water that raises its boiling temperature. The hotter water correspondingly cooks food in a shorter time, although the effect is not significant unless the lid is held down as on a pressure cooker.

77. The boiling point of water is higher in a nuclear reactor because of increased pressure. The reactor behaves like a pressure cooker.

78. After a geyser has erupted, it must refill and then undergo the same heating cycle. If the rates of filling and heating don't change, then the time to boil to the eruption stage will be the same.

79. Water in the pressurized radiator doesn't boil, even when its temperature exceeds 100°C (like water in a pressure cooker). But when the radiator cap is suddenly removed, pressure drops and the high-temperature water immediately boils. Do not have your head above a hot radiator when removing the cap!

80. Yes, ice can be much colder than 0°C, which is the temperature at which ice will melt when it absorbs energy. The temperature of an ice-water mixture in equilibrium is 0°C. Iced tea, for example, is 0°C.

81. The moisture on your skin freezes only at a temperature below 0°C because it contains salt. Very cold ice in contact with your hand freezes the moisture on your skin and bonding takes place between your skin and the ice. That's why it's sticky.

82. Both freezing point and melting points are the same for a pure substance.

83. Snowfall certainly is possible on very cold days. But when snow forms, the temperature of the air increases due to the change of state of the H_2O from gas to solid or from liquid to solid. So one's observation is warmness when snowing, and one's misinterpretation is therefore that snowfall can't happen if it is cold. (Similarly, it is a fact that our ears continue to grow all through life. So old people usually have big ears. Some people who see children with big ears mistakenly say they are destined to have a long life.)

84. The water that freezes is pure water. Melt the ice and you'll have pure water.

85. The weight of the ice above crushes ice crystals at the bottom, making a liquid layer upon which the glacier slides.

86. Regelation would not occur if ice crystals weren't open structured. The pressure of the wire on the open network of crystals caves them in and the wire follows. With the pressure immediately above the wire relieved, the molecules again settle to their low energy crystalline state. Energy given up by the water that refreezes above the wire is conducted through the wire thickness to melt the ice being crushed beneath. The more conductive the wire, the faster regelation occurs. For an insulator like string, regelation won't occur at all. Try it and see!

87. The wood, because its greater specific heat capacity means it will release more energy in cooling. Due to the metal blocks greater conductivity, it will do its melting of ice more quickly.

88. The H_2O absorbs energy in the change of phase from ice to water. If this energy is supplied by the surrounding air, then the temperature of the surrounding air is decreased.

89. Your eyeglasses are colder than the inside air and condensation of the air in the room occurs on your eyeglasses—another example of Figure 17.8.

90. Water in the soda expands when it turns to ice, bulging the ends of the soda can.

91. Sugar doesn't freeze with the water in the punch, so half-frozen punch has the sugar of the original mixture—twice the original concentration.

92. Condensation occurs on the cold coils, which is why the coils drip water.

93. The practice of wrapping newspaper around ice in an icebox is inadvisable, unless one only wants to make the ice last longer at the expense of reducing the cooling effect. The insulating newspaper slows the melting process, which diminishes the extraction of heat from the surroundings. The surroundings are cooled principally because the ice melts. To inhibit this melting is to reduce the desired cooling process.

94. The temperature of nearby air decreases due to energy absorbed by the melting ice.

95. Every gram of water that undergoes freezing releases 80 calories of thermal energy to the cellar. This continual release of energy by the freezing water keeps the temperature of the cellar from going below 0°C. Sugar and salts in the canned goods prevent them from freezing at 0°C. Only when all the water in the tub freezes will the temperature of the cellar go below 0°C and then freeze the canned goods. The farmer must, therefore, replace the tub before or just as soon as all the water in it has frozen.

96. The answer to this is similar to the previous answer, and also the fact that the coating of ice acts as an insulating blanket. Every gram of water that freezes releases 80 calories, much of it to the fruit; the thin layer of ice then acts as an insulating blanket against further loss of heat.

97. The device is a heat pump. In both modes of operation, it is moving heat from a cooler to a warmer place.

98. Dogs have no sweat glands (except between the toes for most dogs) and therefore cool by the evaporation of moisture from the mouth and the respiratory tract. So dogs literally cool from the inside out when they pant.

99. Open ended.

Think and Discuss

100. Alcohol produces more cooling because of its higher rate of evaporation.

101. When a wet finger is held to the wind, evaporation is greater on the windy side, which feels cool. The cool side of your finger is windward.

102. Hot coffee poured into a saucer cools because (1) the greater surface area of the coffee permits more evaporation to take place, and (2) by the conservation of energy, the internal energy that heats the saucer comes from the coffee, cooling it.

103. In this hypothetical case evaporation would not cool the remaining liquid because the energy of exiting molecules would be no different than the energy of molecules left behind. Although internal energy of the liquid would decrease with evaporation, energy per molecule would not change. No temperature change of the liquid would occur. (The surrounding air, on the other hand, would be cooled in this hypothetical case. Molecules flying away from the liquid surface would be slowed by the attractive force of the liquid acting on them.)

104. Water leaks through the porous canvas bag, evaporating from its outer surface and cooling the bag. The motion of the car increases the rate of evaporation and therefore the rate of cooling, just as blowing over a hot bowl of soup increases the rate at which soup cools (Think and Discuss 102).

105. You can add heat without changing temperature when the substance is undergoing a change of phase.

106. You can add heat to ice when it's temperature is below 0°C without melting it. When it reaches 0°C, then additional heat melts it.

107. You can withdraw heat without changing temperature when the substance is undergoing a change of phase.

108. The pressure of surrounding water acts like a pressure cooker and prevents boiling.

109. The predominant gas in a bubble of boiling is H_2O. Did you think this was a tricky question?

110. This is another example that illustrates Figure 17.8. Water vapor in the warm air condenses on the outer surfaces of the cold metal coils of the unit.