18 Thermodynamics

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In the photo opener, it is a pleasure to show Dan Johnson, active in a physics classroom. Dan is better known to environmentalists as Huey D. Johnson, founder of both The Trust for Public Land, and currently Resource Renewal Institute. Dan and I have been close friends since we met in graduate school at Utah State University back in the 1960s. Friends from Sweden, P.O. Zetterberg and Barbara and Tomas Brage take Dan's demonstration a giant step further! And Norwegian friends Ole Anton Haugland and Asge Mellem show an intriguing way to blow up a toy balloon.

These photos, followed by a personal profile of Kelvin, begin this chapter.

In keeping with the preceding chapters on heat, this chapter focuses on the environment. Particular emphasis is given to the atmosphere. What do most people talk about in casual conversations? The weather, of course. This chapter provides some physics insights that underlie the weather.

After several years in Hawaii and viewing hot lava flowing into the ocean, I have always been struck by the failure of onlookers to correctly answer my question, "Why is the lava so hot?" This is addressed in Practice Page 78, *Our Earth's Hot Interior*. There are trace amounts of radioactive materials in common rock. In common granite, for example, there are 4 parts per million uranium, 13 parts per million of thorium, and 4 parts per million of potassium. In one year the energy liberated by these radioactive atoms in a 1-kg sample is about 0.03 J. This information is the basis of the Practice Page.

The only weight-loss plan endorsed by the First Law of Thermodynamics: Burn more calories than you consume and you will lose weight—guaranteed.

Gaining in popularity are geothermal heat pumps that move heat from beneath Earth's surface into homes in winter. Whereas conventional furnaces and air conditioners heat air by means of combustion and chill it through mechanical compression, the geothermal pump circulates fluid through pipes buried underground. In winter, the pump in effect pulls heat out of the ground and pushes it into the home. The Earth's warmth is then distributed throughout the building, typically via an air-duct system. In the cooling mode, the process is reversed. They're proving to be very economical.

Watch also for the rise in the popularity of fuel cells.

The topics absolute zero and internal energy were introduced in Chapter 15 and merit more detail in this chapter. This chapter concludes Part 3 and is not prerequisite to chapters that follow. It may be skipped if a brief treatment of heat is required.

Practicing Physics Book:
- Absolute Zero

Problem Solving Book:

Yes, thermodynamics problems!

Next-Time Questions:
•Lamp Efficiency •Airplane Air Conditioners •Twice as Hot •Nellie's Fuel •Whopped Can

Hewitt-Drew-It! Screencast: •*Thermodynamics*

SUGGESTED LECTURE PRESENTATION

Absolute Zero

Review the temperature scales and lead into the thermodynamic temperature scale. If you did not discuss "Celsius, the Village Tailor," related in the suggested lecture for Chapter 15, this would be the time to do so. Begin by considering the ordering of a piece of hot apple pie and then being served cold pie—ice cold pie, at 0°C. Suppose you ask the waiter to put the pie in the oven and heat it up. How hot? Say twice as hot. Question: What will be the temperature of the pie? Move your class to the "check-your-neighbor" routine. Change your mind about the initial 0°C piece of pie and ask if the problem is easier if you begin with, say, a 10°C piece of pie. Tell your class to beware of neighbors who say the problem is simplified, and the answer is 20°C. This should spark interest. Now you're ready for "Celsius, the Village Tailor" story.

> Celsius, the Village Tailor: Hold a measuring stick against the wall of the lecture room (so that the bottom of the vertically-oriented stick is about 1 meter above the floor) and state that you are Celsius, the village tailor, and that you measure the heights of your customers against the stick, which is firmly fastened to the wall. You state that there is no need for the stick to extend to the floor, nor to the ceiling, for your shortest and tallest customers fall within the extremities of the stick. Mention that all tailors using the same method could communicate meaningfully with each other about the relative heights of their customers providing the measuring sticks in each shop were fastened the same distance above the "absolute zero" of height. It just so happens that the distance to the floor, the "absolute zero," is 273 notches—the same size notches on the stick itself. Then one day, a very short lady enters your shop and stands against the wall, the top of her head coinciding with the zero mark on the measuring stick. As you take her zero reading, she comments that she has a brother who is twice her height. Ask the class for the height of her brother. Then ask for the temperature of the twice-as-hot apple pie. When this is understood, ask why the pie will not *really* be 273°C. Or that for the initially 10°C pie, the temperature will not really be 293°C. (We've simplified here, omitting the role of energy in any phase changes.)

Internal Energy

Distinguish internal energy from temperature. A neat example is the 4th-of-July-type sparklers, even if you've mentioned it earlier. The sparks that fly from the firework and strike your face have temperatures about 2000°C, but they don't burn. Why? Because the energy of the sparks is extremely low. They have a low internal energy. It is the amount of energy you receive that burns, not the ratio of energy/molecule. Even with a high ratio (high temperature), if a relatively few molecules are involved, the energy transfer is low. (Again, this is similar to the high voltage of a balloon rubbed against your hair. It may have thousands of volts, which is to say thousands of joules per charge. But if there are a relatively small number of charges, the total energy they carry is small.)

First Law of Thermodynamics

Introduce the first law of thermodynamics by citing the findings of Count Rumford (Chapter 15 personal profile): when cannon barrels were being drilled and became very hot, it was friction of the drills that produced the heating. In accord with the definition of work, *force* x *distance*, cite how the metal is heated by the frictional force x distance over the various parts of the drill motion. Have your students rub their hands together and feel them warm up. Or warm part of the chair they sit on by rubbing.

Follow this up with the account of Joule with his paddle wheel apparatus to measure the mechanical equivalent of heat. Of interest is Joule's attempt to extend this experiment to a larger scale while on his honeymoon in Switzerland. Joule and his bride honeymooned near the Chamonix waterfall. According to Joule's conception of heat, the gravitational potential energy of the water at the top should go into increasing the internal energy of the water when at the bottom. Joule made a rough estimate of the increased difference in water temperature at the bottom of the waterfall. His measurements did not substantiate his predictions, however, because considerable cooling occurred due to evaporation as the water fell through the air. Without this added complication, however, his predictions would have been supported. What happens to the temperature of a penny, after all, when you transfer the KE of a swinging hammer to it? Likewise with water. Emphasize that the first law is simply the law of energy conservation for thermal systems.

Adiabatic Processes

Cite the opposite processes of compression and expansion of air and how each affects the temperature of the air. It's easy to see that compressing air into a tire warms the air; and also that when the same air expands through the nozzle in escaping, it cools. Discuss cloud formation as moist air rises, expands, and cools.

> CLASS DEMONSTRATION: Blow on your hands first with wide-open mouth, and then with puckered lips so the air expands. This is a first-hand demo of adiabatic cooling!

If you have a model of an internal combustion engine, as indicated in Figure 18.13, strongly consider showing and explaining it in class. Many of your students likely have little idea of the process. (It still amazes me that internal combustion automobile engines are as quiet as they are!)

Meteorology and the First Law

Discuss the adiabatic expansion of rising air in our atmosphere. Ask if it would be a good idea on a hot day when going for a balloon ride to only wear a T-shirt. Or would it be a good idea to bring warm clothing on a balloon ride? A glance at Figure 18.6 will be instructive.

Discuss the Check Question in the text about yanking down a giant dry-cleaner's garment bag from a high altitude and the changes in temperature it undergoes. Quite interesting.

There is more to Chinook winds than is cited in the text. As Figure 18.7 suggests, warm moist air that rises over a mountain cools as it expands, and then undergoes precipitation where it is gains latent heat energy as vapor changes phase to liquid (rain) or solid (snow). Then when the energetic dry air is compressed as it descends on the other side of the mountain, it is appreciably warmer than if precipitation hadn't occurred. Without the heat given to the air by precipitation, it would cool a certain amount in adiabatically expanding and warm the same amount in adiabatically compressing, with have no net increase in temperature.

Discuss temperature inversion and the role it plays in air pollution; or at least in confining air pollution. On the matter of pollution, even rain is polluted. Acid rain has wrecked havoc with the environment in many parts of the world. Interestingly enough, pure rainwater is naturally acidic. Ever-present carbon dioxide dissolves in water vapor to form carbonic acid. Decomposing organic matter, volcanoes, and geysers can release sulfur dioxides that form sulfuric acid. Lightning storms can cause nitric acid formation. The environmental problem of acid rain, however, is not the small amount caused by natural sources. Fossil fuel combustion is the largest single source of acid-producing compounds. On an almost amusing note, it isn't the destruction of vast forests or poisoning of wildlife or the eroding of works of art that have evoked the loudest public outcry—acid rain dulls the high-tech finishes on automobiles, and *that*, for many proud auto owners, is going too far!

On pollution: Romans in ancient times smelted lead in great open-air furnaces. Recent borings in the Greenland ice core suggest pollution from those smelters equaled that of the later Industrial Revolution.

If you haven't crunched soda pop cans in the lecture for the previous chapter, do it now. And relate it to the reduced pressure needed on turbine blades in a steam turbine. This is shown by Erik and Allison Wong in the 3 photos on page 346. 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" back in 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 Figure 18.14—the reason for condensation in a steam turbine—to reduce pressure on the backside of the turbine blades.

Second Law

Introduce the second law by discussing Think and Discuss 86 about immersing a hot tea cup in a large container of cold water. Stress that if the cup were to become even warmer at the expense of the cold water becoming cooler, the first law would not be violated. You're on your way with the second law.

According to my friend Dave Wall who worked for a couple of years in the Patent Office in Washington, D.C., the greatest shortcoming of would-be inventors was their lack of understanding the first and second laws of thermodynamics. The Patent Office has long been besieged with schemes that promise to circumvent these laws. This point is worth discussion, which you can direct to Carnot's efficiency equation and its consequences, like why better fuel economy is achieved when driving on cold days. [Remember in pre-SI days we talked of "mileage"—now it's fuel economy, because "kilometerage" just doesn't have the right ring yet.]

> CHECK QUESTION: Temperatures must be expressed in kelvins when using the formula for ideal efficiency, but may be expressed in either Celsius or kelvins for Newton's law of cooling. Why? [In Carnot's equation, ratios are used; in Newton's law of cooling, only differences.]
>
> CHECK QUESTION: Now there are new "electronic bulbs" that use a quarter of the energy that standard bulbs use to emit the same amount of light (these bulbs generate a radio signal that mixes with the same gas used in conventional fluorescent lamps). Can it be said that these bulbs generate less heat? [Yes, of course.]
>
> CHECK QUESTION: Still common incandescent lamps are typically rated only 5 to 10% efficient, and common fluorescent lamps are only 20% efficient. Now we say that incandescent lamps are 100% heat efficient. Isn't this contradictory? [5 to 10% and 20% efficient as *light* sources, but 100% efficient as *heat* sources. All the energy input, even that which becomes light, very quickly becomes heat.]

Ask why for ratios of temperatures, kelvins must be used. For differences either kelvins or Celsius may be used, for the difference is the same either way.

Efficiency points

When windows of a car are open, air drag is increased. With windows closed, as when the air conditioner is operating, air drag is decreased. At some driving speed, keeping the air con operating compensates for the extra fuel used to overcome air drag. So driving at low speeds with air con on consumes more fuel, while driving at high speed with air con on and windows closed, consumes less fuel. Another point; cars with tinted windows use less gasoline because they need less power for air conditioning.

Entropy

Conclude your treatment of this chapter with your best ideas on entropy—the measure of messiness.

Answers and Solutions for Chapter 18

Reading Check Questions

1. The meaning is “movement of heat.”
2. Thermodynamics is mainly concerned with macroscopic processes.
3. Its volume decreases by 1/273 for each 1°C temperature change.
4. Its pressure decreases by 1/273 for each 1°C temperature change.
5. Volume approaches zero.
6. Lowest temperature is -273°C; 0 K.
7. Principle concern is changes in energy.
8. The first law is a restatement of the conservation of energy.
9. A system refers to a well-defined group of atoms, molecules, or objects.
10. Heat added equals change in internal energy plus work done.
11. When work is done, both internal energy and temperature increases.
12. The adiabatic condition is that no heat enters or leaves the system.
13. Increase when work done on the system; decrease when work done by the system.
14. Air temperature rises as heat is added or pressure increased.
15. Air temperature rises (or falls) as pressure increases (or decreases).
16. Temperature of rising air falls; but rises for sinking air.
17. Temperature inversion is a condition wherein upper regions of air are warmer than lower regions.
18. Adiabatic processes apply to all fluids.
19. Heat never of itself flows from a cold object to a hot object.
20. Three processes are gaining heat, converting some to mechanical work, and expelling the remainder.
21. Thermal pollution is expelled heat that is undesirable.
22. Only some of the work done on an engine operating between two temperatures can be converted to work, with the rest expelled.
23. Condensation reduces pressure on the backside of turbine blades, allowing a net force to turn them while water is being recycled.
24. High-quality energy is organized; lower-quality, disorganized.
25. High-quality energy tends to transform into lower-quality energy.
26. Natural systems tend to transform from higher to lower quality energy states.
27. A measure of disorder is called entropy.
28. No exceptions occur for the first law of thermodynamics; but exceptions do occur for the second law.
29. The third law states that no system can have its absolute temperature reduced to zero.
30. The zeroth law states that if two systems, each in thermal equilibrium with a third system are in equilibrium with each other.

Think and Do

31. Yes, collapse occurs, although not as violent, when warm water is used for the pan.

32. Its warmth is due to both the blow of the hammer and the work done by the wood to bring the nail to a stop.

Plug and Chug

33. Ideal efficiency = $\frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}}$ = (3000 K – 300 K)/(3000 K) = 90%.

34. Ideal efficiency = $\frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}}$ = (2700 K – 200 K)/(2700 K) = 93%.

Think and Solve

35. Converting to absolute temperatures, 600°C = 273 + 600 = 873 K; 320°C = 273 + 320 = 593 K. Then ideal efficiency is (873 - 593)/873 = 0.32 or 32%. If Celsius values were inserted into the equation, an incorrect 47% would result. Not so!

36. Converting to kelvins; 25°C = 298 K; 4°C = 277 K. So Carnot efficiency = $\frac{T_h - T_c}{T_h} = \frac{298 - 277}{298} =$ 0.07, or 7%. This is very low, which means that large volumes of water (which there are) must be processed for sufficient power generation.

37. If by “twice as cold” she means one-half the absolute temperature, the temperature would be (1/2)(273 +10) = 141.5 K. To find how many Celsius degrees below 0°C this is, first subtract 141.5 K from 273 K; this is 273 K - 141.5 K = 131.5 K below the freezing point of ice, or **-131.5°C**. (Or simply, 141.5 K - 273 K = -131.5°C.) *Very* cold!

38. Adiabatic compression would heat the confined air by about 10°C for each kilometer decrease in elevation. That means the -35°C air would be heated 100°C and have a ground temperature of about (-35 + 100) = 65°C. (This is 149°F, roasting hot!)

39. (a) Wally’s mistake is not converting to kelvins. 300°C = 273 + 300 = 573K, and 25°C = 273 + 25 = 298 K. (b) Then ideal efficiency is (573 K – 298 K)/(573 K) = 0.48, or 48%.

40. Heating each kg of water through 3 degrees takes 3°C × 1 kg × 4,184 J/kg°C = 12,550 J. The number of joules of heat supplied to the water each second is 1.5×10^8, so the number of kilograms of water heated each second is (1.5×10^8 J)/(12,550 J/kg) = 12,000 kg. Or, $Q = cm\Delta T$ = (4,184 J/kg°C)(1 kg)(3°C) = 12,552 kg (about 12,000 kg).

41. The work the hammer does on the nail is $F \times d$, and the temperature change of the nail can be found from $Q = cm\Delta T$. First, we get everything into convenient units for calculating: 6.0 g = 0.006 kg; 8.0 cm = 0.08 m. Then we see that $F \times d$ = 600 N × 0.08 m = 48 J, and 48 J = (0.006 kg)(450 J/kg·°C)(ΔT) which we can solve to get ΔT = 48J/(0.006 kg × 450 J/kg ·°C) = 17.8°C. (You will notice a similar effect when you remove a nail from a piece of wood. The nail that you pull out is noticeably warm.)

42. Seven is most likely because there are more combinations that give seven than any other sum. Of the 36 possible combinations, 6 gives seven.

Think and Explain

43. In the case of the 500-degree oven it makes a lot of difference. 500 kelvins is 227°C, quite a bit different than 500°C. But in the case of the 50,000-degree star, the 273 increments either way makes practically no difference. Give or take 273, the star is still 50,000 K or 50,000°C when rounded off.

44. No, for as in the previous exercise, a difference of 273 in 10,000,000 is insignificant.

45. Not ordinarily. They undergo the same change in *internal energy*, which translates to the same temperature change when both objects are the same mass and composed of the same material.

46. Its absolute temperature is 273 K. Double this and you have 546 K. When expressed in Celsius; 546 - 273 = 273 °C.

47. You do work on the liquid when you vigorously shake it back and forth, which increases its internal energy. This is noted by an increase in temperature. (In the mid-nineteenth century, James Joule, by measuring the temperature of a liquid before and after doing known work with a stirring paddle, revealed what he called “the mechanical equivalent of heat,” a discovery that led to the general law of energy conservation.)

48. You do work in compressing the air, which increases its internal energy. This is evidenced by an increase in temperature.

49. The change in internal energy is 100 J – 80 J = 20 J.

50. The pump gets hot because you are *compressing* the air within. The tire valve feels cool because the escaping air is *expanding*. These are adiabatic processes.

51. You compress air when you blow up a balloon, warming the balloon. When air expands in leaving, it cools. Both are adiabatic processes.

52. Gas pressure increases in the can when heated, and decreases when cooled. When heated the faster-moving molecules hit the can’s wall harder and more often. When cooled, they hit less hard and less often.

53. It warms because it is adiabatically compressed.

54. Solar energy. The terms renewable and non-renewable really refer to time scales for regeneration—tens of years for wood versus millions of years for coal and oil.

55. Solar energy is the ultimate source of energy.

56. It is advantageous to use steam as hot as possible in a steam-driven turbine because the efficiency is higher if there is a greater difference in temperature between the source and the sink (see Sadi Carnot's equation in the chapter).

57. In accord with Carnot's equation, efficiency is higher with greater difference in temperature between the heat source (combustion chamber in the engine) and sink (air surrounding the exhaust). Also, lowering the temperature of the environment also increases the ideal efficiency.

58. When the temperature is lowered in the reservoir into which heat is rejected, efficiency increases; substitution of a smaller value of T_{cold} into $(T_{hot} - T_{cold})/T_{hot}$ will confirm this. (Re-express the equation as $1 - T_{cold}/T_{hot}$ to better see this.)

59. Only when the sink is at absolute zero (0 K) will a heat engine have an ideal efficiency of 100%.

60. As in the preceding exercise, inspection will show that decreasing T_{cold} will contribute to a greater increase in efficiency than by increasing T_{hot} by the same amount. For example, let T_{hot} be 600K and T_{cold} be 300K. Then efficiency = (600 - 300)/(600) = 1/2. Now let T_{hot} be increased by 200K. Then efficiency = (800 - 300)/(800) = 5/8. Compare this with T_{cold} decreased by 200K, in which case efficiency = (600 - 100)/(600) = 5/6, which is clearly greater.

61. No. In this case the heat sink is also in the room. That's why the condensation coils are in a region *outside* the region to be cooled. Temperature of the room actually increases because the refrigerator motor warms the surrounding air.

62. Yes. Unlike the cooling wished for in the previous exercise, the energy given to the room by the open oven raises room temperature.

63. You *are* cooled by the fan, which blows air over you to increase the rate of evaporation from your skin, but you are a small part of the overall system, which warms.

64. Work must be done to establish a temperature difference between the inside of the refrigerator and the surrounding air. The greater the temperature difference to be established, the more work and hence more energy is consumed. So the refrigerator uses more energy when the room is warm rather than cold.

65. It doesn't violate the second law of thermodynamics because an external agent does work on the system.

66. The gas is more compact—density increases.

67. You do work in compressing the gas, which increases the internal energy.

68. Most people know that electric lights are inefficient when converting electrical energy into light energy, so they are surprised to learn there is a 100% conversion of electrical energy to thermal energy. If the building is being heated electrically, the lights do a fine job of heating, and it is not at all wasteful to keep them on when heating is needed. It is a wasteful practice if the air conditioners are on and cooling is desired, for the energy input to the air conditioners must be increased to remove the extra thermal energy given off by the lights.

69. It does what heat engines do, namely convert energy of one kind (solar) into mechanical energy (the rocking of the bird).

70. As the gas streams out of the nozzle, some of its kinetic energy becomes kinetic energy of the rocket, so temperature drops. Expansion of the gas also contributes to its lower temperature.

71. Energy in the universe is tending toward unavailability with time. Hotter things are cooling as cooler things are warming. If this is true, the universe is tending toward a common temperature, the so-called

"heat death," when energy can no longer do work. (But we don't know for sure that the laws of thermodynamics apply to the universe as a whole, since we don't understand the ultimate source of the vast churning energy that is now apparent throughout the universe. Nature may have some surprises for us!)

72. The universe is moving toward a more disordered state.

73. Adiabatic parcels occur in both the atmosphere and the oceans.

74. More energy would be used to extract the energy than would be available from it. So although extracting ocean energy is possible, it is not practical, and cannot produce net power.

75. There are more ways for molecules in the liquid phase to move, resulting in more random and chaotic motion.

76.No, the entropy principle has not been violated because the order of the salt crystals is at the expense of a greater disorder of the water in the vapor state after evaporation. Even if we confine the system to the crystals themselves, there would be no violation of entropy because there is work input to the system by sunlight or other means.

77. No, the freezing of water is not an exception to the entropy principle because work has been put into the refrigeration system to prompt this change of state. There is actually a greater net disorder when the environment surrounding the freezer is considered.

78. Entropy of the overall system, of which the chicken is a small part, increases. So when the larger system is taken into account, there is no violation of the principle of entropy.

79. Such machines violate at least the second law of thermodynamics, and the first law as well. These laws are so richly supported by so many experiments over so long a time that the Patent Office wisely assumes that there is a flaw in the claimed invention rather than in the laws of thermodynamics.

Think and Discuss

80.A given amount of mechanical energy can be easily and commonly converted to thermal energy; any body moving with kinetic energy that is brought to rest by friction transforms all its kinetic energy into thermal energy (for example, a car skidding to rest on a horizontal road). The converse is not true, however. In accord with the 2nd law of thermodynamics, only a fraction of a given amount of thermal energy can be converted to mechanical energy. For example, even under ideal conditions, less than half of the heat energy provided by burning fuel in a power plant can go into mechanical energy of electric generators.

81. No—internal energy, unlike temperature, is not an average quantity.

82. When a blob of air rises in the atmosphere it expands while doing work on the surrounding lower-pressure air. This work output reduces internal energy, as evidenced by a lower temperature. Hence the temperature of air at the elevation of mountain tops is usually less than down below.

83. A breeze on a hot day reduces the thickness of this thermal blanket, and even removes it, which is followed by overheating of the body. The reverse outcome occurs on a cold day when your skin feels colder as a result of the breeze.

84. Blood leaving your brain is warmer than blood that enters, carrying away excess heat generated by brain activity so your head doesn't overheat. Overheating diminishes concentration!

85. To say one place is twice as hot as another is to say the temperatures given are absolute temperatures. A temperature in Boston of 40°F is about 4°C, which is 277K. Twice 277K is 554K, which is 281°C, which is higher than 500°F. So an 80°F day in Florida is not twice as hot as a 40°C day in Boston!

86.This transfer would not violate the 1st law because energy has been transferred without loss or gain. It would violate the 2nd law because internal energy will not freely transfer from a cooler to a warmer object.

87. The term pollution refers to an undesirable by-product of some process. The desirability or undesirability of a particular by-product is relative, and depends on the circumstances. For example, using waste heat from a power plant to heat a swimming pool could be desirable whereas using the same heat to warm a trout stream could be undesirable.

88. The can is crushed by atmospheric pressure when vapor pressure in the can has been significantly reduced. Reduction of vapor pressure in the can is accomplished by condensation of the vapor on the surface of water entering the opening in the can. If that water is boiling, then it supplies vapor at about the same rate as condensation occurs, resulting in no net condensation and no crunching. But even hot water, if its temperature is less than 100°C, will result in net condensation and a crushed can.

89. Some of the electric energy that goes into lighting a lamp is transferred by conduction and convection to the air, some is radiated at invisible wavelengths ("heat radiation") and converted to internal energy when it is absorbed, and some appears as light. Very little energy is converted to light in an incandescent lamp, with somewhat more in a fluorescent lamp. Even then, all of the energy that takes the form of light is converted to internal energy when the light is absorbed by materials upon which it is incident. So by the 1st law, all the electrical energy is ultimately converted to internal energy. By the second law, organized electrical energy degenerates to the more disorganized form, internal energy. The thermodynamics laws are not violated.

90. It is fundamental in that it governs the general tendency throughout nature to move from order to disorder, yet it is inexact in the sense that it is based on probability, not certainty.

91. A perpetual motion machine would work only if there were no friction, *zero* friction. In practice, in the large-scale world there is always friction, so perpetual motion would require that energy increase, violating the conservation of energy principle. Atoms and molecules, on the other hand, are in continual perpetual motion, rebounding elastically from one anther, so they don't dissipate energy or "run down."

92. Your classmate isn't distinguishing between perpetual motion and perpetual motion machines. Your classmates is correct about perpetual motion being the normal state of the universe, but what is not possible is a perpetual motion machine that puts out more energy (including friction loss) than is put in.

93. (a) Yes, very likely. Two heads would come up on average one throw out of four. (b) Not likely. The chance for ten coins to come up all heads is only about 1 in 1000. (c) Extremely unlikely, even with a lifetime of trying. The laws of thermodynamics are based on the statistics of large numbers.