7 Energy

Swedish physics teacher Christine Lindstrom heads the photo openers for this chapter, followed by Neil de Grasse Tyson, whose profile is in Chapter 30. I see Neil as the new Carl Sagan, both for his devotion to astrophysics, his keen wit, and the message he conveys about science to the public. Photo 3 is of friends who started a small physics products company in 1981, which I've watched grow since then. Today Vernier Software and Technology, based in Portland, is a major supplier of quality equipment for classroom and lab physics. Photo 4 is an impressive array of photovoltaic cells at Nellis Air Force Base near Las Vegas, NV, that supply about 25% of the Base's electrical needs. On days when air conditioning isn't needed, the panels supply 100% of the Base's needs. The panels were installed in just 26 weeks in 2007 by the SunPower Corporation. The system generates 14.2 megawatts and is the largest photovoltaic instillation in the U.S (though only the 25th largest in the world). Nearly all the bigger ones are in Spain. Germany, however leads the world in photovoltaic power, interestingly, not in the brightest part of sunshine reaching Earth. Germany also leads in wind turbine power, not the windiest part of the world. Citizen resolve is the explanation. Hooray for Germany and other parts of the world who take alternative energies seriously. Robots in space, of course, nicely feed on sunshine.

The profile on Emilie du Chatelet cites the controversy in England and continental Europe about the "oomph" of objects in contact. Emilie helped settle the controversy by distinguishing between momentum (v) and kinetic energy (v^2), an interesting story.

The section, Recyled Energy, on page 119 interestingly advocates using the thermal energy generated by power plants to heating homes and other buildings. New York City and Copenhagen are two cities that do this quite successfully. Rooftop energy is contrasted in Figures 7.24 and 7.25 where water and sunlight are successfully caught and employed. I have been advocating dry-rock geothermal power (Figure 7.26) for nearly every edition of Conceptual Physics, going back more than a quarter century. Why it hasn't come to the forefront puzzles me. Is the fact that there's no fuel to sell a factor? The Internet will provide the latest in which of the several power contenders rises to the occasion.

Not mentioned in the text are biofuels and the prospects for algae-based fuel oil. Algae can be grown on nonagricultural land, absorb carbon dioxide, and the oils they produce can be refined into conventional transportation fuels that can be distributed using existing infrastructures. Given that the energy market is $1 trillion a year globally, biofuels will likely be a substantial player.

Helen Yan, one of my proud teaching protégés, shows pulley systems in Figure 7.20 on page 121. Helen was my student before continuing physics at U.C. Berkeley and San Francisco State University. In addition to her "rocket-science" occupation at Lockheed Martin in Sunnyvale, CA, she teaches the same conceptual physics course at CCSF that she took from me many years ago.

Another protégé of mine is Tenny Lim, drawing a bow in Figure 7.10. Tenny is also a “rocket scientist” (Figure 7.5) and lead designer of the descent stage that lowered Curiosity onto the Martian surface in 2012 (her profile is in Chapter 10). David Willey points out that only about 60% to 75% of the PE of a drawn bow goes into the KE of an arrow, depending on the type of bow. The rest of the energy heats the bow. Similarly, only about 30% of the energy of firearms is transferred to the projectiles they fire. The rest heats the firearm. This poses a problem with sustained fire in machine guns, where the bore thermally expands so bullets no longer take the rifling and tip over and over in flight just as though they were fired from a smooth bore. Hence the water cooling for machine guns.

Practicing Physics Book:
- Work and Energy
- Conservation of Energy
- Momentum and Energy
- Energy and Momentum

Problem Solving Book:
Many problems on energy

Laboratory Manual:
- An Uphill Climb *Work on an Inclined Plane* (Experiment)
- The Fountain of Fizz *Physics in the Soda Pop Geyser* (Demonstration)
- Dropping the Ball *Conservation of Energy During Free Fall* (Experiment)

Next-Time Questions (in the Instructor Resource DVD):
- Bumpy Tracks
- Roller Coaster
- Long Cannon
- Skidding Distance
- Oomph
- Ball Toss
- Cannonball
- Falling Balls

Hewitt-Drew-It! Screencasts:
- *Work and Potential Energy*
- *Work-Energy Theorem*
- *Energy of Acrobats*
- *Machines and Energy*
- *Potential and Kinetic Energy*
- *Conservation of Energy*
- *Ballistic Pendulum*

SUGGESTED LECTURE PRESENTATION

Begin by standing on a chair against a wall with an extended heavy pendulum bob held at the tip of your nose. Say nothing. Release the bob and let it swing out, then back to your nose. Don’t flinch. Then comment on your confidence in physical laws and lead into a distinction between potential and kinetic energy. Point out where the bob is moving fastest it is lowest, and where it is highest it doesn’t move at all. The bob transforms energy of motion to energy of position in cyclic fashion. Allow the pendulum to swing to-and-fro while you’re talking. Its motion decays. Why? Then point out the transformation of energy from the moving bob to the molecules of air that are encountered, and to the molecules in the bending string or wire at the pivot point. The energy of the pendulum will end up as heat energy. I quip that on a very hot day, somebody, somewhere, is swinging a giant pendulum to-and-fro.

Work

Define work and compare it to impulse of the previous chapter. In both case, the effect of exerting a force on something depends on how long the force acts. In the previous chapter, how long was meant as time, and we spoke of impulse. In this chapter, how long is meant as distance, and we speak of work. Cite the examples of the drawn slingshot and the long barreled cannon, where the added length produces greater speed. We described this greater speed in terms of greater momentum. Now we describe this greater speed in terms of greater energy—that is, greater KE.

> CHECK QUESTION: Is work done when a weightlifter (Figure 7.3) holds a barbell stationary above her head? [Yes and no. With each contraction of the weightlifter’s heart, a force is exerted

> through a distance on her blood and so does work on the blood. But this work is not done on the barbell.]

Work-Energy Theorem

When discussing whether or not work is done, be sure to specify *done on what*. If you push a stationary wall, you may be doing work on your muscles (that involve forces and distances in flexing), but you do no work *on the wall*. Key point: If work is done on something, then the energy of that something changes. Distinguish between the energy one expends in doing things, and the work that is actually done *on* something.

> CHECK QUESTION: When a car slows down due to air resistance, does its KE decrease? [Most certainly!]
>
> CHECK QUESTION: Which is greater, 1 joule or 1 newton? [Whoops! The comparison is silly, for they're units of completely different things—work and force.] An idea about the magnitude of 1 joule is that it's the work done in vertically lifting a quarter-pound hamburger with cheese (approximately 1 N) one meter.

Power

A watt of power is the work done in vertically lifting a quarter-pound hamburger with cheese (approximately 1 N) one meter in one second.

Potential Energy

Return to your pendulum: With the pendulum at equilibrium show how the force necessary to pull it sideways (which varies with the angle made by the string) is very small compared to the force necessary to lift it vertically (its weight). Point out that for equal elevations, the arced path is correspondingly longer than the vertical path—with the result that the product of the applied force and distance traveled—the work done—is the same for both cases. (Without overdoing it, this is a good place to let your students know about integral calculus—how calculus is required to add up the work segments that continuously increase in a nonlinear way.) Then discuss the work needed to elevate the ball in Figure 7.6.

> CHECK QUESTIONS: Does a car hoisted for lubrication in a service station have PE? How much work will raise the car twice as high? Three times as high? How much more PE will it have in these cases?

You can give the example of dropping a bowling ball on your toe—first from a distance of a couple of centimeters above your toe, then to various distances up to 1 m. Each time, the bowling ball would do more work on your toe because it would transfer more gravitational potential energy when released.

Kinetic Energy

Relate force × distance = ΔKE to examples of pushing a car, and then to braking a car as treated in the text. You may do Problem 3 (about skidding distance as a function of speed) at this point.

To a close approximation, skidding force is independent of speed. Hence change in KE is approximately equal to change in skidding distance. When the car's brakes are applied, the car's kinetic energy is changed into internal energy in the brake pads, tire, and road as they become warmer.

You may or may not at this point preview future material by relating the idea of the KE of molecules and the idea of temperature. State that molecules in a substance having the same temperature have the same average KE. If the masses of the molecules are the same, then it follows that the speeds of the molecules are the same. But what if the masses are different, for example in a sample of gas composed of light and heavy molecules at the same temperature? Which molecules would move faster? (If you shook a container of billiard balls mixed with Ping-Pong balls so that both kinds of balls had the same kinetic energy, which would move faster in the container? If an elephant and a mouse run with the same kinetic energy, which means that both will do the same amount of work if bumping into the door of a barn, can you say which of the two is running faster?) You might consider the demonstration of inhaling helium and talking at this point—particularly if you are not including the chapters on sound in your course design. Relate the higher temperature due to the faster moving helium molecules to the higher temperature in a bugle when faster moving air is blown through it.

Energy Conservation

Discuss Figures 7.9 and 7.11 and then return to your pendulum. Explain how the kinetic energy and hence, the speed of the bob at the bottom of its swing is equal to the speed it would have if dropped vertically through the same height.

> CHECK QUESTION: Refer to Figure 7.6 in "inclines" (a) and (b): How does the speed of the ball compare at ground level when released from equal elevations? [It is impressive that the speeds will be the same. The lesser acceleration down the sloped ramp is compensated by a longer time. But return to the situation and ask how the *times* to reach the bottom compare and be prepared for an incorrect response, "The same!" (NOT true!) Quip and ask if the colors and temperatures will also be the same. Straight-forward physics can be confusing enough!]
>
> DEMONSTRATION: Preview electricity and magnetism and bring out the horseshoe magnet hand-cranked generator that lights up the lamp shown ahead in photo 5 that opens Chapter 25 (Sheron Snyder producing light). Have student volunteers attest to the fact that more work is needed to turn the crank when the lamp is connected than when it is not. Then relate this to Think and Discuss 101 (about the car burning more fuel with lights on).

When gasoline combines with oxygen in a car's engine, the chemical potential energy stored in the fuel is converted mainly into molecular KE (thermal energy). Some of this energy in effect is transferred to the piston and some of this causes motion of the car.

We think of electric cars as something new. But they were more popular than gasoline-driven cars in the late 19th and early 20th century. They could go all day on a single charge and move a driver around a city with ease. They required no hand crank to start and had no gears to shift. But back then speed limits were set below 20 mph to accommodate horse-drawn carriages. After World War I these limits were lifted and gasoline powered cars began to dominate. Sooner of later when most cars go electric, we'll be going full-circle!

Go over the Check Yourself question about fuel economy on page 117—very important. (I pose the same question on my exams, which to the student is the *definition* of what's important!) This is a pre-hybrid question about cars. As a side point, gas economy is increased when tires are inflated to maximum pressures, where less flattening of the tire occurs as it turns. The very important point of this exercise is the upper limit possible.

I extend this idea of an upper limit to the supposed notion that certain gadgets attached to automobile engines will give phenomenal performance—so much in fact, (tongue in cheek) that the oil companies have gobbled up the patents and are keeping them off the market. Charlatans stand ready to benefit from this public perception, and offer the public a chance to invest in their energy producing machines. They prey on people who are ignorant of or do not understand the message of the energy conservation law. You can't get something for nothing. You can't even break-even, because of the inevitable transformation of available energy to heat. For more on such charlatans, read Bob Park's book, *Voodoo Science*.

Scams that sell energy-making machines rely on funding from deep pockets and shallow brains!

Solar Power

Government subsidies for solar power have made Europe the world's solar capitol. Even the first large solar plant in the U.S, Solar One in Nevada, belongs to Acciona, a Spanish company that generates electricity that it sells to NV Energy, the regional utility. Nevada One uses solar thermal, where sunlight is reflected onto long rows of pipes that make steam to run a 64-megawatt power plant. The mirrors were made in Germany.

Another method of getting electricity from sunshine is employed by SunCatchers, huge mirrors at Sandia National Labs in New Mexico that power Stirling engines held at the focal points of the arrays. Electricity is made by pistons in the engines. It is the most efficient system for converting photon energy to grid-ready AC power.

Nearly all big solar plants lack a storage system, a means of storing some of the heat produced during daylight hours for release when the Sun isn't shining. Check the commercial solar plant near Granada in Spain where sunlight from mirrors is used to heat molten salt. In the evening the salt cools and gives back heat to make steam. In this way, molten salt is used for storage. As the book mentions, energy can be stored in compressed air, which a plant in Alabama is using, and which has been used in Germany for decades. Another way is with batteries. With a storage system of one kind or another, electricity can be generated continuously on demand.

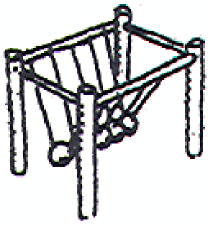
Solar photovoltaic panels are expensive to produce and normally provide efficiencies of 10 to 20%. Parabolic troughs that turn heat to steam get about 24%. Researchers can produce PV panels somewhat more than 40% efficient. Check the Internet for current information.

Efficiency

It should be enough that your students become acquainted with the idea of efficiency, so I don't recommend setting the plow too deep for this topic. The key idea to impart is that of useful energy. To say that an incandescent lamp is 10% efficient is to say that only 10% of the energy input is converted to the useful form of light. All the rest goes to heat. But even the light energy converts to heat upon absorption. So all the energy input to an incandescent lamp is converted to heat. This means that it is a 100% efficient *heater* (but not a 100% device for emitting light)! Much more efficient light sources are treated in Chapter 23 and 30 (CFLs and LEDs).

Dark Energy: Not discussed in the text is the current serious speculation of dark energy, which is postulated to be speeding up the expanding universe. You may want to discuss this current finding, which may be one of the most important discoveries in science in the past quarter century.

> NEXT-TIME QUESTION: Think and Discuss 120, when you've shown the swinging ball apparatus, Newton's cradle, in class (available from Arbor Scientific. P1-6001.)



Answers and Solutions for Chapter 7

Reading Check Questions

1. Energy is most evident when it is changing.
2. Force multiplied by distance is work.
3. No work is done in pushing on a stationary wall, as in Figure 7.4.
4. It is the same, for the product of each is the same; (50 kg)(2 m) = (25 kg)(4 m).
5. Energy enables an object to do work.
6. The same power when both are raised in the same time; Twice the power for the lighter sack raised in half the time.
7. It would have twice because distance raised is twice.
8. Twice-as-massive car has twice the PE.
9. PE is significant when it changes, does work or transforms to energy of another form.
10. Four times as much (as $2^2 = 4$).
11. Four times as much work; 4 times as much stopping distance (as $2^2 = 4$).
12. ΔKE = work done = (100 N – 70 N)(10 m) = (30 N)(10 m) = 300 N·m = 300 J.
13. Speed has little or no effect on friction.
14. Its gain in KE will equal its decrease in PE, 10 kJ.
15. Immediately before hitting the ground its initial PE becomes KE. When it hits the ground its energy becomes thermal energy.
16. The source of the energy of sunshine is fusion power in the Sun.
17. Recycled energy is the reemployment of energy that otherwise would be wasted.
18. A machine can multiply input force or input distance, but NEVER input energy.
19. As force is increased, distance is decreased by the same factor.
20. The end moving 1/3 as far can exert 3 times the input force, 150 N.
21. Efficiency would be 100%.
22. Efficiency will be 60%.
23. The Sun is the source of these energies.
24. Radioactivity is the source of geothermal energy.
25. Like electricity, hydrogen is a carrier of energy, not a source. That's because it takes energy to separate hydrogen from molecules.

Think and Do

26. The temperature of the sand is more after shaking than before. You do work on the sand in shaking it, which increases its temperature.

27. Some of the basketball's energy is transferred to the tennis ball by compression. During decompressing, the basketball pushes the tennis ball upward, while the tennis ball pushes the basketball downward. So PE of the bounced basketball is less and PE of the tennis ball is more, but both add to equal the original PEs of the balls before dropped.

Plug and Chug

28. $W = Fd$ = (5 N)(1.2 m) = 6 N·m = 6 J.
29. $W = Fd$ = (2.0 N)(1.2 m) = 2.4 N·m = 2.4 J.
30. $W = Fd$ = (20 N)(3.5 m) = 70 N·m = 70 J.
31. $W = Fd$ = (500 N)(2.2 m) = 1100 N·m = 1100 J, which is also the gain in PE.
32. $P = W/t$ = (100 J)/(2 s) = 50 W.
33. $P = W/t = Fd/t$ = (500 N)(2.2 m)/(1.4 s) = 786 W.
34. PE = mgh = (3.0 kg)(10 N/kg)(2.0 m) = 60 N·m = 60 J.
35. PE = mgh = (1000 kg)(10 N/kg)(5 m) = 50,000 N·m = 50,000 J.
36. KE = ½ mv^2 = ½(1.0 kg)(3.0 m/s)^2 = 4.5 kg(m/s)^2 = 4.5 J.
37. KE = ½ mv^2 = ½(84 kg)(10 m/s)^2 = 4200 kg(m/s)^2 = 4200 J.
38. W = ΔKE = Δ½ mv^2 = ½(3.0 kg)(4.0 m/s)^2 = 24 J.
39. From W = ΔKE, ΔKE = Fd = (5000 N)(500 m) = 2,500,000 J.
40. Efficiency = energy output/energy input x 100% = (40 J)/(100 J) = 0.40 or 40%

Think and Solve

41. Work = ΔE = Δmgh = 300 kg × 10 N/k × 6 m = **18,000 J**.

42. (a) You do $F \times d$ = 100 N × 10 m = 1000 J of work.
(b) Because of friction, net work on the crate is less. ΔKE = Net work = net force × distance = (100 N – 70 N)(10 m) = 300 J.
(c) So the rest, 700 J, goes into heating the crate and floor.

43. At three times the speed, it has 9 times (3^2) the KE and will skid 9 times as far—135 m. Since the frictional force is about the same in both cases, the distance has to be 9 times as great for 9 times as much work done by the pavement on the car.

44.PE + KE = Total E; KE = 10,000 J – 1000 J = 9000 J.

45. From $F \times d = F' \times d/4$, we see $F' = 4F$ = 200 N.

46. Your input work is 50 J, so 200-N × h = 50 J. h = 50/200 = 0.25 m.

47.$(F \times d)_{\text{in}} = (F \times d)_{\text{out}}$
$F \times$ 2 m = 5000 N × 0.2 m
F = [(5000 N)(0.2 m)]/2 m = **500 N**.

48.$(F \times d)_{\text{in}} = (F \times d)_{\text{out}}$
$(100\text{ N} \times 10\text{ cm})_{\text{in}} = (? \times 1\text{ cm})_{\text{out}}$
So we see that the output force and weight held is **1000 N** (less if efficiency < 100%).

49. Power = Fd/t = (50N)(8m)/(4s) = 100J/1s = 100 watts.

50. The initial PE of the banana is transformed to KE as it falls. When the banana is about to hit the water, all of its initial PE becomes KE.
From $\text{PE}_0 = \text{KE}_f \Rightarrow mgh = 1/2\, mv^2 \Rightarrow v^2 = 2gh \Rightarrow v = \sqrt{2gh}.$

Think and Rank

51. a. B, A, C
    b. C, B, A
    c. C, B, A
52. a. C, B=D, A
    b. C, B=D, A
    c. A, B=D, C
53. a. D, B, C, E, A
    b. D, B, C, E, A
    c. A, E, C, B, D
54. B=C, A (same as two supporting ropes)

Think and Explain

55. Stopping a lightly loaded truck of the same speed is easier because it has less KE and will therefore require less work to stop. (An answer in terms of impulse and momentum is also acceptable.)
56. You do no work because you haven't exerted more than a negligible force on the backpack in the direction of motion. Also, the energy of the backpack hasn't changed. No change in energy means no work done.

57. Your friend does twice as much work ($4 \times {}^1/2 > 1 \times 1$).

58. Although no work is done on the wall, work is nevertheless done on internal parts of your body (which generate heat).

59. More force is required to stretch the strong spring, so more work is done in stretching it the same distance as a weaker spring.

60. Work done by each is the same, for they reach the same height. The one who climbs in 30 s uses more power because work is done in a shorter time.

61. The PE of the drawn bow as calculated would be an overestimate (in fact, about twice its actual value) because the force applied in drawing the bow begins at zero and increases to its maximum value when fully drawn. It's easy to see that less force and therefore less work is required to draw the bow halfway than to draw it the second half of the way to its fully-drawn position. So the work done is not *maximum force × distance drawn*, but *average force × distance drawn*. In this case where force varies almost directly with distance (and not as the square or some other complicated factor) the average force is simply equal to the initial force + final force, divided by 2. So the PE is equal to the average force applied (which would be approximately half the force at its full-drawn position) multiplied by the distance through which the arrow is drawn.

62. When a rifle with a long barrel is fired, more work is done as the bullet is pushed through the longer distance. A greater KE is the result of the greater work, so of course, the bullet emerges with a greater velocity. (Note that the force acting on the bullet is not constant, but decreases with increasing distance inside the barrel.)

63. Agree, because speed itself is relative to the frame of reference (Chapter 3). Hence $\frac{1}{2} mv^2$ is also relative to a frame of reference.

64. The KE of the tossed ball relative to occupants in the airplane does not depend on the speed of the airplane. The KE of the ball relative to observers on the ground below, however, is a different matter. KE, like velocity, is relative.

65. You're both correct, with respect to the frames of reference you're inferring. KE is relative. From your frame of reference she has considerable KE for she has a great speed. But from her frame of reference her speed is zero and KE also zero.

66. The energy goes mostly into frictional heating of the air.

67. Without the use of a pole, the KE of running horizontally cannot easily be transformed to gravitational PE. But bending a pole stores elastic PE in the pole, which *can* be transformed to gravitational PE. Hence the greater heights reached by vaulters with very elastic poles.

68. The KE of a pendulum bob is maximum where it moves fastest, at the lowest point; PE is maximum at the uppermost points. When the pendulum bob swings by the point that marks half its maximum height, it has half its maximum KE, and its PE is halfway between its minimum and maximum values. If we define PE = 0 at the bottom of the swing, the place where KE is half its maximum value is also the place where PE is half its maximum value, and KE = PE at this point. (By energy conservation: Total energy = KE + PE.)

69. If the ball is given an initial KE, it will return to its starting position with that KE (moving in the other direction!) and hit the instructor. (The usual classroom procedure is to release the ball from the nose at rest. Then when it returns it will have no KE and will stop short of bumping the nose.)

70. Yes to both, relative to Earth, because work was done to lift it in Earth's gravitational field and to impart speed to it.

71. In accord with the theorem, once moving, no work is done on the satellite (because the gravitational force has no component parallel to motion), so no change in energy occurs. Hence the satellite cruises at a constant speed.

72. According to the work-energy theorem, twice the speed corresponds to 4 times the energy, and therefore 4 times the driving distance. At 3 times the speed, driving distance is 9 times as much.

73. The answers to both (a) and (b) are the same: When the direction of the force is perpendicular to the direction of motion, as is the force of gravity on both the bowling ball on the alley and the satellite in circular orbit, there is no force component in, or parallel to, the direction of motion and no work is done by the force.

74. On the hill there is a component of gravitational force parallel to the car's motion. This component of force does work on the car. But on the level, there is no component of gravitational force parallel to the direction of the car's motion, so the force of gravity does no work in this case.

75. The string tension is everywhere perpendicular to the bob's direction of motion, which means there is no component of tension parallel to the bob's path, and therefore no work done by the tension. The force of gravity, on the other hand, has a component parallel to the direction of motion everywhere except at the bottom of the swing, and does work, which changes the bob's KE.

76. The fact that the crate pulls back on the rope in action-reaction fashion is irrelevant. The work done on the crate by the rope is the horizontal component of rope force that acts on the crate multiplied by the distance the crate is moved by that force—period. How much of this work produces KE or thermal energy depends on the amount of friction acting.

77. The 100 J of potential energy that doesn't go into increasing her kinetic energy goes into thermal energy—heating her bottom and the slide.

78. A Superball will bounce higher than its original height if thrown downward, but if simply dropped, no way. Such would violate the conservation of energy.

79. When a Superball hits the floor some of its energy is transformed to heat. This means it will have less kinetic energy after the bounce than just before and will not reach its original level.

80. Kinetic energy is a maximum as soon as the ball leaves the hand. Potential energy is a maximum when the ball has reached its highest point.

81. The design is impractical. Note that the summit of each hill on the roller coaster is the same height, so the PE of the car at the top of each hill would be the same. If no energy were spent in overcoming friction, the car would get to the second summit with as much energy as it starts with. But in practice there is considerable friction, and the car would not roll to its initial height and have the same energy. So the maximum height of succeeding summits should be lower to compensate for friction.

82. You agree with your second classmate. The coaster could just as well encounter a low summit before or after a higher one, so long as the higher one is enough lower than the initial summit to compensate for energy dissipation by friction.

83. Sufficient work occurs because with each pump of the jack handle, the force she exerts acts over a much greater distance than the car is raised. A small force acting over a long distance can do significant work.

84. Einstein's $E = mc^2$. (More on this in Chapters 34 and 35).

85. When the mass is doubled with no change in speed, both momentum and KE are doubled.

86. When the velocity is doubled, the momentum is doubled and the KE is increased by a factor of four. Momentum is proportional to speed, KE to speed squared.

87. Both have the same momentum, but the faster 1-kg one has the greater KE.

88. The momentum of the car is equal in magnitude but opposite in direction in the two cases—not the same since momentum is a vector quantity.

89. Zero KE means zero speed, so momentum is also zero.

90. Yes, if we're talking about only you, which would mean your speed is zero. But a system of two or more objects can have zero net momentum, yet have substantial total KE.

91. Not at all. For two objects of the same KE, the one of greater mass has greater momentum. (The mathematical relationship is $p^2 = 2m \times \text{KE}$.)

92. Net momentum before the lumps collide is zero and after collision is zero. Momentum is indeed conserved. Kinetic energy after is zero, but was greater than zero before collision. The lumps are warmer after colliding because the initial kinetic energy of the lumps transforms into thermal energy. Momentum has only one form. There is no way to "transform" momentum from one form to another, so

it is conserved. But energy comes in various forms and can easily be transformed. No single form of energy such as KE need be conserved.

93. Scissors and shears are levers. The applied force is normally exerted over a short distance for scissors so that the output force is exerted over a relatively long distance (except when you want a large cutting force like cutting a piece of tough rope, and you place the rope close to the “fulcrum” so you can multiply force). With metal-cutting shears, the handles are long so that a relatively small input force is exerted over a long distance to produce a large output force over a short distance.

94. Energy is transformed into nonuseful forms in an inefficient machine, and is “lost” only in the loose sense of the word. In the strict sense, it can be accounted for and is therefore not lost.

95. An engine that is 100% efficient would not be warm to the touch, nor would its exhaust heat the air, nor would it make any noise, nor would it vibrate. This is because all these are transfers of energy, which cannot happen if all the energy given to the engine is transformed to useful work. (Actually, an engine of 100% efficiency is not even possible in principle. We discuss this in Chapter 18.)

96. Your friend is correct, for changing KE requires work, which means more fuel consumption and decreased air quality.

97. In accord with energy conservation, a person who takes in more energy than is expended stores what’s left over as added chemical energy in the body—which in practice means more fat. One who expends more energy than is taken in gets extra energy by “burning” body fat. An undernourished person who performs extra work does so by consuming stored chemical energy in the body—something that cannot long occur without losing health—and life.

Think and Discuss

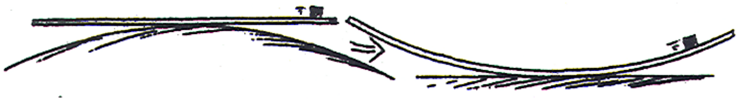
98. Once used, energy cannot be regenerated, for it dissipates into less useful forms in the environment—inconsistent with the term “renewable energy.” Renewable energy refers to energy derived from renewable resources—trees, for example.

99. As world population continues to increase, energy production must also increase to provide decent standards of living. Without peace, cooperation, and security, global-scale energy production likely decreases rather than increases.

100. Both will have the same speed. This is easier to see here because both balls convert the same PE to KE. (Think energy when solving motion problems!)

101. Yes, a car burns more gasoline when its lights are on. The overall consumption of gasoline does not depend on whether or not the engine is running. Lights and other devices are run off the battery, which “runs down” the battery. The energy used to recharge the battery ultimately comes from the gasoline.

102. Except for the very center of the plane, the force of gravity acts at an angle to the plane, with a component of gravitational force along the plane—along the block’s path. Hence the block goes somewhat against gravity when moving away from the central position, and moves somewhat with gravity when coming back. As the object slides farther out on the plane, it is effectively traveling “upward” against Earth’s gravity, and slows down. It finally comes to rest and then slides back and the process repeats itself. The block slides back and forth along the plane. From a flat-Earth point of view the situation is equivalent to that shown in the sketch.



103. Solar energy is merely energy from the Sun. Solar power, like power in general, is the *rate* at which energy is transferred. Solar power is therefore the same from hour to hour, whereas the amount of solar energy depends on the amount of time energy is transferred.

104. If KEs are the same but masses differ, then the ball with smaller mass has the greater speed. That is, $^1/2\, Mv^2 = {}^1/2\, mV^2$. Likewise with molecules, where lighter ones move faster on the average than more massive ones. (We will see in Chapter 15 that temperature is a measure of average molecular KE—lighter molecules in a gas move faster than same-temperature heavier molecules.)

105. A car with windows open experiences more air drag, which causes more fuel to be burned in maintaining motion. This may more than offset the saving from turning off the air conditioner.

106. A machine can multiply force or multiply distance, both of which can be of value.

107. Your friend may not realize that mass itself is congealed energy, so you tell your friend that much more energy in its congealed form is put into the reactor than is taken out from the reactor. About 1% of the mass that undergoes fission is converted to energy of other forms.

108. The work that the rock does on the ground is equal to its PE before being dropped, *mgh* = 100 joules. The force of impact, however, depends on the distance that the rock penetrates into the ground. If we do not know this distance we cannot calculate the force. (If we knew the time during which the impulse occurs we could calculate the force from the impulse-momentum relationship—but not knowing the distance or time of the rock's penetration into the ground, we cannot calculate the force.)

109. When we speak of work done, we must understand work done *on what, by what*. Work is done on the car by applied forces that originate in the engine. The work done by the road in reacting to the backward push of the tires is equal to the product of the applied force and the distance moved, not the *net* force that involves air resistance and other friction forces. When doing work, we think of applied force; when considering acceleration, we think of net force. Actually, the frictional forces of the internal mechanisms in the car, and to some extent the road itself are doing negative work on the car. The zero total work explains why the car's speed doesn't change.

110. When air resistance is a factor, the ball will return with less speed (as discussed in Chapter 4). It therefore will have less KE. You can see this directly from the fact that the ball loses mechanical energy to the air molecules it encounters, so when it returns to its starting point and to its original PE, it will have less KE. This does not contradict energy conservation, for energy is transformed, not destroyed.

111. The ball strikes the ground with the *same* speed, whether thrown upward or downward. The ball starts with the same energy at the same place, so they will have the same energy when they reach the ground. This means they will strike with the same speed. This is assuming negligible air resistance, for if air resistance is a factor, then the ball thrown upward will lose more energy to the air in its longer path and strike with somewhat less speed. Another way to look at this is to consider Figure 3.8 back on page 50; in the absence of air resistance, the ball thrown upward will return to its starting level with the same speed as the ball thrown downward. Both hit the ground at the same speed (but at different *times*).

112. Tension in the string supporting the 10-kg block is 100 N (which is the same all along the string). So Block B is supported by two strands of string, each 100 N, which means the mass of Block B is twice that of Block A. So Block B has a mass of 20 kg.

113. The other 15 horsepower is supplied by electric energy from the batteries (which are ultimately recharged using energy from gasoline).

114. In a conventional car, braking converts KE to heat. In a hybrid car, braking charges up the batteries. In this way, braking energy can soon be transformed to KE.

115. The question can be restated; Is $(30^2 - 20^2)$ greater or less than $(20^2 - 10^2)$? We see that $(30^2 - 20^2) = (900 - 400) = 500$, which is considerably greater than $(20^2 - 10^2) = (400 - 100) = 300$. So KE changes more for a given Δv at the higher speed.

116. If an object has KE, then it must have momentum—for it is moving. But it can have potential energy without being in motion, and therefore without having momentum. And every object has "energy of being"—stated in the celebrated equation $E = mc^2$. So whether an object moves or not, it has some form of energy. If it has KE, then with respect to the frame of reference in which its KE is measured, it also has momentum.

117. (a) In accord with Newton's second law, the component of gravitational force that is parallel to the incline in B produces an acceleration parallel to the incline. (b) In accord with the work-energy theorem, that parallel force component multiplied by the distance the ball travels is equal to the change in the ball's KE.

118. The physics here is similar to that of the ball on the horizontal alley in the previous problem. (a) Tension in the string is everywhere perpendicular to the arc of the pendulum, with no component of tension force parallel to its motion. (b) In the case of gravity, a component of gravitational force on the pendulum exists parallel to the arc, which does work and changes the KE of the pendulum. (c) When the pendulum is at its lowest point, however, there is no component of gravitational force parallel to motion. At that instant of motion, gravity does no work (as it doesn't when the pendulum hangs at rest when the sting is vertical).

119. This is very similar to the previous two problems. In circular orbit, the force of gravity is everywhere perpendicular to the satellite's motion. With no component of force parallel to its motion, no work is done and its KE remains constant.

120. There is more to the "swinging balls" problem than momentum conservation, which is why the problem wasn't posed in the previous chapter. Momentum is certainly conserved if two balls strike with momentum $2mv$ and one ball pops out with momentum $m(2v)$. That is, $2mv = m2v$. We must also consider KE. Two balls would strike with $2(^1/2\, mv^2) = mv^2$. The single ball popping out with twice the speed would carry away twice as much energy as was put in:
$^1/2\, m(2v)^2 = {}^1/2\, m(4v^2) = 2mv^2$. So popping out with twice its initial energy is clearly a conservation of energy no-no!

121. In the popular sense, conserving energy means not wasting energy. In the physics sense energy conservation refers to a law of nature that underlies natural processes. Although energy can be wasted (which really means transforming it from a more useful to a less useful form), it cannot be destroyed. Nor can it be created. Energy is transferred or transformed, without gain or loss. That's what a physicist means in saying energy is conserved.

122. The rate at which energy can be supplied is more central to consumers than the amount of energy that may be available, so "power crisis" more accurately describes a short-term situation where demand exceeds supply. (In the long term, the world may be facing an energy crisis when supplies of fuel are insufficient to meet demand.)