Summary

- Work and energy are scalar quantities.
- Power is the rate at which work is done.
- Gravitational potential energy is the energy stored in a mass based on its separation from the surface of Earth.
- Kinetic energy is the energy of a mass because of its motion.
- Elastic potential energy is stored in a spring that has been either compressed or stretched.
- The law of conservation of energy states that the total energy of a system remains the same.
- Mechanical energy refers to the sum total of potential energy and kinetic energy.
- Work done by friction converts mechanical energy into heat energy.

Practice Exercises

In each case, select the choice that best answers the question or completes the statement.

1. If value of an object is tripled, its kinetic energy is
   (A) 1/9
   (B) 1/3
   (C) 3
   (D) 6
   (E) 9

   times its original value.

Questions 2–4

A person having a mass of 60 kilograms exerts a horizontal force of 200 newtons in pushing a 90-kilogram object a distance of 6 meters along a horizontal floor. He does this at constant velocity in 3 seconds.

2. The weight of this person is, in newtons, approximately,
   (A) 40
   (B) 90
   (C) 200
   (D) 400
   (E) 600
3. The work done by this person is, in joules,
   (A) 540
   (B) 1,080
   (C) 1,200
   (D) 3,600
   (E) 5,400
4. The force of friction is
   (A) exactly 60 N
   (B) between 60 and 90 N
   (C) exactly 90 N
   (D) exactly 200 N
   (E) greater than 200 N

Questions 5 and 6

The 1,000-newton weight of a pile driver falls freely from rest; it drops 25 meters, strikes a steel beam, and drives it 3 centimeters into the ground.

5. The kinetic energy of the weight of the pile driver just before it hits the beam is, in newton · meters,
   (A) 3,000
   (B) 25,000
   (C) 75,000
   (D) 200,000
   (E) 800,000
6. The speed of the weight just before hitting the beam is, in meters per second, approximately
   (A) 0.25
   (B) 3
   (C) 25
   (D) 22
   (E) 64
7. A spring with a force constant $k = 500$ N/m is stretched by a distance of 0.2 meter. How many joules of potential energy are stored in the spring?
   (A) 500 J
   (B) 250 J

(C) 10 J
(D) 5 J
(E) 0.4 J

8. Which of the following is equivalent to 1 joule?
(A) kg · m/s
(B) kg · m/s^2
(C) kg · m^2/s^2
(D) kg · $m^2 \cdot s^2$
(E) kg · s^2/m

9. If a spring is doubled in length, then the potential energy stored in the spring will be
(A) doubled
(B) halved
(C) quadrupled
(D) quartered
(E) the same as before

10. A 5 kg mass is moving horizontally at 10 m/s along a horizontal floor that can be considered frictionless. It collides with a light spring at rest. The spring compresses by 5 meters until the mass stops. What is the value of the spring constant *k*?
(A) 10 N/m
(B) 15 N/m
(C) 20 N/m
(D) 250 N/m
(E) 4.5 N/m

Answer Key

1. **(E)**	5. **(B)**	9. **(C)**
2. **(E)**	6. **(D)**	10. **(C)**
3. **(C)**	7. **(C)**	
4. **(D)**	8. **(C)**	

Answers Explained

1. **E** Kinetic energy = $\frac{1}{2}m\mathbf{v}^2$. For a given object the kinetic energy is proportional to the square of its speed. When the speed is multiplied by 3, the kinetic energy is multiplied by 3^2, or 9.

2. **E** The weight of an object on Earth is the gravitational pull of Earth on it and is equal to the product of the object's mass and the value of the acceleration of a freely falling object:

$$\begin{aligned} \text{weight} &= mg \\ &= (60\text{ kg})(9.8\text{ m/s}^2) \\ &= 600\text{ N} \end{aligned}$$

3. **C** Work done on an object is equal to the product of the force exerted on the object and the distance moved in the direction of the force:

$$\begin{aligned} \text{work} &= \text{force} \times \text{distance} \\ &= (200\text{ N})(6\text{ m}) \\ &= 1{,}200\text{ joules} \end{aligned}$$

4. **D** Since the force exerted is horizontal, none of it is used to overcome gravity. Also, since the velocity remains constant, none of the force (and work done) is used to give the object kinetic energy. Therefore all of the 200-N force used is required to overcome friction.
5. **B** The kinetic energy that the weight has just before it hits is equal to the potential energy it had at the top just before falling. The potential energy at the top = weight × height:

$$\text{PE} = 1{,}000\text{ N} \times 25\text{ m} = 25{,}000\text{ N} \cdot \text{m}$$

6. **D** To calculate the speed of an object falling freely from rest if we know the distance of fall:

$$\begin{aligned} \mathbf{v}^2 &= 2\text{g}d = 2 \times 9.8\text{ m/s}^2 \times 25\text{ m} \\ \mathbf{v} &= 22\text{ m/s} \end{aligned}$$

7. **C** The potential energy is given by PE = $\frac{1}{2}kx^2$. If we substitute the given information, we can easily calculate that PE = $\frac{1}{2}(500\text{ N/m})(0.2\text{ m})^2 = 10$ joules.
8. **C** Since 1 J = 1 N · m and 1 N · m = 1 (kg · m/s^2) · m, 1J = 1 kg · m^2/s^2.
9. **C** The potential energy stored in a stretched spring is given by PE = $\frac{1}{2}kx^2$. If the spring is doubled in length, the stored potential energy will increase by four times (quadruple).
10. **C** In this problem, use the law of conservation of mechanical energy. The total energy before is equal to the total energy after. In this case, the total energy before the interaction is just the kinetic energy of the mass, KE = $\frac{1}{2}m\mathbf{v}^2 = \frac{1}{2}(5\text{ kg})(10\text{ m/s})^2 = 250$ J. This kinetic energy now does work to compress the spring by 5 meters. Thus all of the kinetic energy of the mass is converted into elastic potential energy:

$$250\text{ J} = \tfrac{1}{2}k(5\text{ m})^2$$

and we easily calculate that $k = 20$ N/m.

Problems & Exercises

7.1 Work: The Scientific Definition

1. How much work does a supermarket checkout attendant do on a can of soup he pushes 0.600 m horizontally with a force of 5.00 N? Express your answer in joules and kilocalories.

2. A 75.0-kg person climbs stairs, gaining 2.50 meters in height. Find the work done to accomplish this task.

3. (a) Calculate the work done on a 1500-kg elevator car by its cable to lift it 40.0 m at constant speed, assuming friction averages 100 N. (b) What is the work done on the lift by the gravitational force in this process? (c) What is the total work done on the lift?

4. Suppose a car travels 108 km at a speed of 30.0 m/s, and uses 2.0 gal of gasoline. Only 30% of the gasoline goes into useful work by the force that keeps the car moving at constant speed despite friction. (See **Table 7.1** for the energy content of gasoline.) (a) What is the magnitude of the force exerted to keep the car moving at constant speed? (b) If the required force is directly proportional to speed, how many gallons will be used to drive 108 km at a speed of 28.0 m/s?

5. Calculate the work done by an 85.0-kg man who pushes a crate 4.00 m up along a ramp that makes an angle of 20.0° with the horizontal. (See **Figure 7.35**.) He exerts a force of 500 N on the crate parallel to the ramp and moves at a constant speed. Be certain to include the work he does on the crate *and* on his body to get up the ramp.

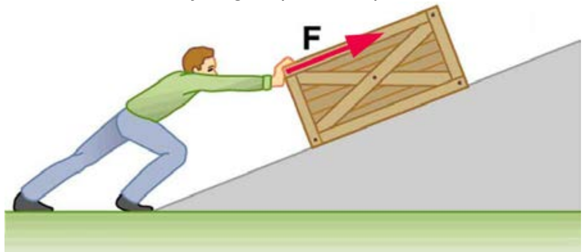


Figure 7.35 A man pushes a crate up a ramp.

6. How much work is done by the boy pulling his sister 30.0 m in a wagon as shown in **Figure 7.36**? Assume no friction acts on the wagon.

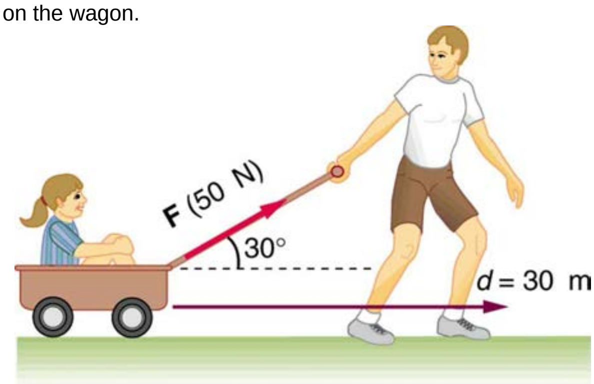


Figure 7.36 The boy does work on the system of the wagon and the child when he pulls them as shown.

7. A shopper pushes a grocery cart 20.0 m at constant speed on level ground, against a 35.0 N frictional force. He pushes in a direction 25.0° below the horizontal. (a) What is the work done on the cart by friction? (b) What is the work done on the cart by the gravitational force? (c) What is the work done on the cart by the shopper? (d) Find the force the shopper exerts, using energy considerations. (e) What is the total work done on the cart?

8. Suppose the ski patrol lowers a rescue sled and victim, having a total mass of 90.0 kg, down a 60.0° slope at constant speed, as shown in **Figure 7.37**. The coefficient of friction between the sled and the snow is 0.100. (a) How much work is done by friction as the sled moves 30.0 m along the hill? (b) How much work is done by the rope on the sled in this distance? (c) What is the work done by the gravitational force on the sled? (d) What is the total work done?

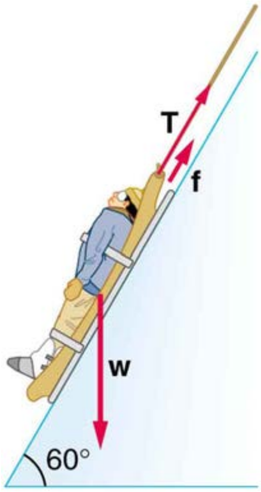


Figure 7.37 A rescue sled and victim are lowered down a steep slope.

7.2 Kinetic Energy and the Work-Energy Theorem

9. Compare the kinetic energy of a 20,000-kg truck moving at 110 km/h with that of an 80.0-kg astronaut in orbit moving at 27,500 km/h.

10. (a) How fast must a 3000-kg elephant move to have the same kinetic energy as a 65.0-kg sprinter running at 10.0 m/s? (b) Discuss how the larger energies needed for the movement of larger animals would relate to metabolic rates.

11. Confirm the value given for the kinetic energy of an aircraft carrier in **Table 7.1**. You will need to look up the definition of a nautical mile (1 knot = 1 nautical mile/h).

12. (a) Calculate the force needed to bring a 950-kg car to rest from a speed of 90.0 km/h in a distance of 120 m (a fairly typical distance for a non-panic stop). (b) Suppose instead the car hits a concrete abutment at full speed and is brought to a stop in 2.00 m. Calculate the force exerted on the car and compare it with the force found in part (a).

13. A car's bumper is designed to withstand a 4.0-km/h (1.1-m/s) collision with an immovable object without damage to the body of the car. The bumper cushions the shock by absorbing the force over a distance. Calculate the magnitude of the average force on a bumper that collapses 0.200 m while bringing a 900-kg car to rest from an initial speed of 1.1 m/s.

14. Boxing gloves are padded to lessen the force of a blow. (a) Calculate the force exerted by a boxing glove on an opponent's face, if the glove and face compress 7.50 cm during a blow in which the 7.00-kg arm and glove are brought to rest from an initial speed of 10.0 m/s. (b) Calculate the force exerted by an identical blow in the gory old days when no gloves were used and the knuckles and face would compress only 2.00 cm. (c) Discuss the magnitude of the force with glove on. Does it seem high enough to cause damage even though it is lower than the force with no glove?

15. Using energy considerations, calculate the average force a 60.0-kg sprinter exerts backward on the track to accelerate from 2.00 to 8.00 m/s in a distance of 25.0 m, if he encounters a headwind that exerts an average force of 30.0 N against him.

7.3 Gravitational Potential Energy

16. A hydroelectric power facility (see **Figure 7.38**) converts the gravitational potential energy of water behind a dam to electric energy. (a) What is the gravitational potential energy relative to the generators of a lake of volume 50.0 km^3 ($\text{mass} = 5.00{\times}10^{13}\text{ kg})$, given that the lake has an average height of 40.0 m above the generators? (b) Compare this with the energy stored in a 9-megaton fusion bomb.

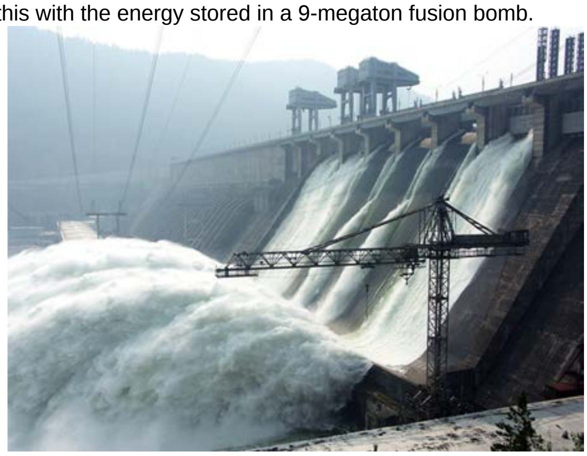


Figure 7.38 Hydroelectric facility (credit: Denis Belevich, Wikimedia Commons)

17. (a) How much gravitational potential energy (relative to the ground on which it is built) is stored in the Great Pyramid of Cheops, given that its mass is about $7 \times 10^9\text{ kg}$ and its center of mass is 36.5 m above the surrounding ground? (b) How does this energy compare with the daily food intake of a person?

18. Suppose a 350-g kookaburra (a large kingfisher bird) picks up a 75-g snake and raises it 2.5 m from the ground to a branch. (a) How much work did the bird do on the snake? (b) How much work did it do to raise its own center of mass to the branch?

19. In **Example 7.7**, we found that the speed of a roller coaster that had descended 20.0 m was only slightly greater when it had an initial speed of 5.00 m/s than when it started from rest. This implies that $\Delta\text{PE} >> \text{KE}_\text{i}$. Confirm this statement by taking the ratio of ΔPE to KE_i . (Note that mass cancels.)

20. A 100-g toy car is propelled by a compressed spring that starts it moving. The car follows the curved track in **Figure 7.39**. Show that the final speed of the toy car is 0.687 m/s if its initial speed is 2.00 m/s and it coasts up the frictionless slope, gaining 0.180 m in altitude.

Figure 7.39 A toy car moves up a sloped track. (credit: Leszek Leszczynski, Flickr)

21. In a downhill ski race, surprisingly, little advantage is gained by getting a running start. (This is because the initial kinetic energy is small compared with the gain in gravitational potential energy on even small hills.) To demonstrate this, find the final speed and the time taken for a skier who skies 70.0 m along a 30^o slope neglecting friction: (a) Starting from rest. (b) Starting with an initial speed of 2.50 m/s. (c) Does the answer surprise you? Discuss why it is still advantageous to get a running start in very competitive events.

7.4 Conservative Forces and Potential Energy

22. A $5.00{\times}10^5\text{-kg}$ subway train is brought to a stop from a speed of 0.500 m/s in 0.400 m by a large spring bumper at the end of its track. What is the force constant k of the spring?

23. A pogo stick has a spring with a force constant of $2.50{\times}10^4\text{ N/m}$, which can be compressed 12.0 cm. To what maximum height can a child jump on the stick using only the energy in the spring, if the child and stick have a total mass of 40.0 kg? Explicitly show how you follow the steps in the **Problem-Solving Strategies for Energy**.

7.5 Nonconservative Forces

24. A 60.0-kg skier with an initial speed of 12.0 m/s coasts up a 2.50-m-high rise as shown in **Figure 7.40**. Find her final speed at the top, given that the coefficient of friction between her skis and the snow is 0.0800. (Hint: Find the distance traveled up the incline assuming a straight-line path as shown in the figure.)

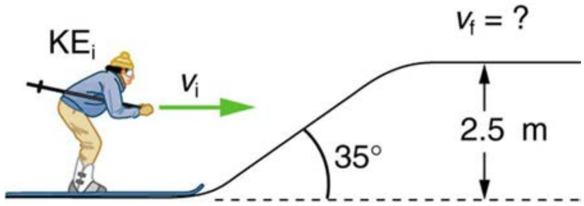


Figure 7.40 The skier's initial kinetic energy is partially used in coasting to the top of a rise.

25. (a) How high a hill can a car coast up (engine disengaged) if work done by friction is negligible and its initial speed is 110 km/h? (b) If, in actuality, a 750-kg car with an initial speed of 110 km/h is observed to coast up a hill to a height 22.0 m above its starting point, how much thermal energy was generated by friction? (c) What is the average force of friction if the hill has a slope 2.5° above the horizontal?

7.6 Conservation of Energy

26. Using values from **Table 7.1**, how many DNA molecules could be broken by the energy carried by a single electron in the beam of an old-fashioned TV tube? (These electrons were not dangerous in themselves, but they did create dangerous x rays. Later model tube TVs had shielding that absorbed x rays before they escaped and exposed viewers.)

27. Using energy considerations and assuming negligible air resistance, show that a rock thrown from a bridge 20.0 m above water with an initial speed of 15.0 m/s strikes the water with a speed of 24.8 m/s independent of the direction thrown.

28. If the energy in fusion bombs were used to supply the energy needs of the world, how many of the 9-megaton variety would be needed for a year's supply of energy (using data from **Table 7.1**)? This is not as far-fetched as it may sound—there are thousands of nuclear bombs, and their energy can be trapped in underground explosions and converted to electricity, as natural geothermal energy is.

29. (a) Use of hydrogen fusion to supply energy is a dream that may be realized in the next century. Fusion would be a relatively clean and almost limitless supply of energy, as can be seen from **Table 7.1**. To illustrate this, calculate how many years the present energy needs of the world could be supplied by one millionth of the oceans' hydrogen fusion energy. (b) How does this time compare with historically significant events, such as the duration of stable economic systems?

7.7 Power

30. The Crab Nebula (see **Figure 7.41**) pulsar is the remnant of a supernova that occurred in A.D. 1054. Using data from **Table 7.3**, calculate the approximate factor by which the power output of this astronomical object has declined since its explosion.

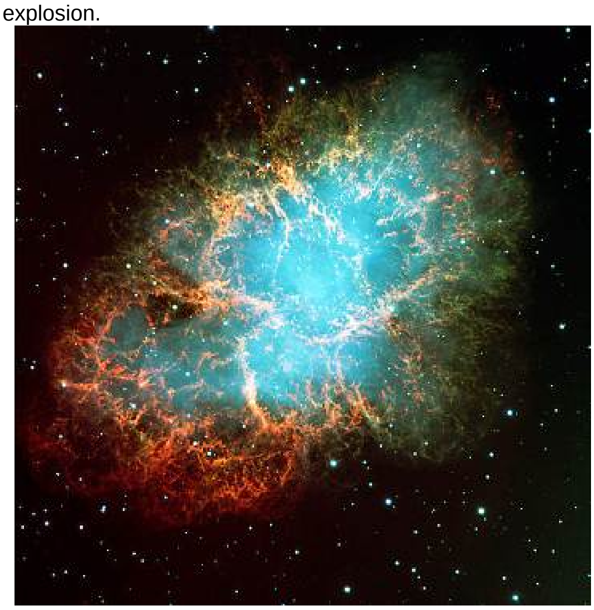


Figure 7.41 Crab Nebula (credit: ESO, via Wikimedia Commons)

31. Suppose a star 1000 times brighter than our Sun (that is, emitting 1000 times the power) suddenly goes supernova. Using data from **Table 7.3**: (a) By what factor does its power output increase? (b) How many times brighter than our entire Milky Way galaxy is the supernova? (c) Based on your answers, discuss whether it should be possible to observe supernovas in distant galaxies. Note that there are on the order of 10^{11} observable galaxies, the average brightness of which is somewhat less than our own galaxy.

32. A person in good physical condition can put out 100 W of useful power for several hours at a stretch, perhaps by pedaling a mechanism that drives an electric generator. Neglecting any problems of generator efficiency and practical considerations such as resting time: (a) How many people would it take to run a 4.00-kW electric clothes dryer? (b) How many people would it take to replace a large electric power plant that generates 800 MW?

33. What is the cost of operating a 3.00-W electric clock for a year if the cost of electricity is $0.0900 per $\text{kW} \cdot \text{h}$?

34. A large household air conditioner may consume 15.0 kW of power. What is the cost of operating this air conditioner 3.00 h per day for 30.0 d if the cost of electricity is $0.110 per $\text{kW} \cdot \text{h}$?

35. (a) What is the average power consumption in watts of an appliance that uses $5.00\ \text{kW} \cdot \text{h}$ of energy per day? (b) How many joules of energy does this appliance consume in a year?

36. (a) What is the average useful power output of a person who does $6.00\times10^{6}\ \text{J}$ of useful work in 8.00 h? (b) Working at this rate, how long will it take this person to lift 2000 kg of bricks 1.50 m to a platform? (Work done to lift his body can be omitted because it is not considered useful output here.)

37. A 500-kg dragster accelerates from rest to a final speed of 110 m/s in 400 m (about a quarter of a mile) and encounters an average frictional force of 1200 N. What is its average power output in watts and horsepower if this takes 7.30 s?

38. (a) How long will it take an 850-kg car with a useful power output of 40.0 hp (1 hp = 746 W) to reach a speed of 15.0 m/s, neglecting friction? (b) How long will this acceleration take if the car also climbs a 3.00-m-high hill in the process?

39. (a) Find the useful power output of an elevator motor that lifts a 2500-kg load a height of 35.0 m in 12.0 s, if it also increases the speed from rest to 4.00 m/s. Note that the total mass of the counterbalanced system is 10,000 kg—so that only 2500 kg is raised in height, but the full 10,000 kg is accelerated. (b) What does it cost, if electricity is $0.0900 per $\text{kW}\cdot\text{h}$?

40. (a) What is the available energy content, in joules, of a battery that operates a 2.00-W electric clock for 18 months? (b) How long can a battery that can supply $8.00\times10^4\ \text{J}$ run a pocket calculator that consumes energy at the rate of $1.00\times10^{-3}\ \text{W}$?

41. (a) How long would it take a 1.50×10^5 -kg airplane with engines that produce 100 MW of power to reach a speed of 250 m/s and an altitude of 12.0 km if air resistance were negligible? (b) If it actually takes 900 s, what is the power? (c) Given this power, what is the average force of air resistance if the airplane takes 1200 s? (Hint: You must find the distance the plane travels in 1200 s assuming constant acceleration.)

42. Calculate the power output needed for a 950-kg car to climb a 2.00° slope at a constant 30.0 m/s while encountering wind resistance and friction totaling 600 N. Explicitly show how you follow the steps in the **Problem-Solving Strategies for Energy**.

43. (a) Calculate the power per square meter reaching Earth's upper atmosphere from the Sun. (Take the power output of the Sun to be $4.00\times10^{26}\ \text{W}$.) (b) Part of this is absorbed and reflected by the atmosphere, so that a maximum of $1.30\ \text{kW/m}^2$ reaches Earth's surface. Calculate the area in km^2 of solar energy collectors needed to replace an electric power plant that generates 750 MW if the collectors convert an average of 2.00% of the maximum power into electricity. (This small conversion efficiency is due to the devices themselves, and the fact that the sun is directly overhead only briefly.) With the same assumptions, what area would be needed to meet the United States' energy needs $(1.05\times10^{20}\ \text{J})$? Australia's energy needs $(5.4\times10^{18}\ \text{J})$? China's energy needs $(6.3\times10^{19}\ \text{J})$? (These energy consumption values are from 2006.)

7.8 Work, Energy, and Power in Humans

44. (a) How long can you rapidly climb stairs (116/min) on the 93.0 kcal of energy in a 10.0-g pat of butter? (b) How many flights is this if each flight has 16 stairs?

45. (a) What is the power output in watts and horsepower of a 70.0-kg sprinter who accelerates from rest to 10.0 m/s in 3.00 s? (b) Considering the amount of power generated, do you think a well-trained athlete could do this repetitively for long periods of time?

46. Calculate the power output in watts and horsepower of a shot-putter who takes 1.20 s to accelerate the 7.27-kg shot from rest to 14.0 m/s, while raising it 0.800 m. (Do not include the power produced to accelerate his body.)

Figure 7.42 Shot putter at the Dornoch Highland Gathering in 2007. (credit: John Haslam, Flickr)

47. (a) What is the efficiency of an out-of-condition professor who does $2.10\times10^5\ \text{J}$ of useful work while metabolizing 500 kcal of food energy? (b) How many food calories would a well-conditioned athlete metabolize in doing the same work with an efficiency of 20%?

48. Energy that is not utilized for work or heat transfer is converted to the chemical energy of body fat containing about 39 kJ/g. How many grams of fat will you gain if you eat 10,000 kJ (about 2500 kcal) one day and do nothing but sit relaxed for 16.0 h and sleep for the other 8.00 h? Use data from **Table 7.5** for the energy consumption rates of these activities.

49. Using data from **Table 7.5**, calculate the daily energy needs of a person who sleeps for 7.00 h, walks for 2.00 h, attends classes for 4.00 h, cycles for 2.00 h, sits relaxed for 3.00 h, and studies for 6.00 h. (Studying consumes energy at the same rate as sitting in class.)

50. What is the efficiency of a subject on a treadmill who puts out work at the rate of 100 W while consuming oxygen at the rate of 2.00 L/min? (Hint: See **Table 7.5**.)

51. Shoveling snow can be extremely taxing because the arms have such a low efficiency in this activity. Suppose a person shoveling a footpath metabolizes food at the rate of 800 W. (a) What is her useful power output? (b) How long will it take her to lift 3000 kg of snow 1.20 m? (This could be the amount of heavy snow on 20 m of footpath.) (c) How much waste heat transfer in kilojoules will she generate in the process?

52. Very large forces are produced in joints when a person jumps from some height to the ground. (a) Calculate the magnitude of the force produced if an 80.0-kg person jumps from a 0.600–m-high ledge and lands stiffly, compressing joint material 1.50 cm as a result. (Be certain to include the weight of the person.) (b) In practice the knees bend almost involuntarily to help extend the distance over which you stop. Calculate the magnitude of the force produced if the stopping distance is 0.300 m. (c) Compare both forces with the weight of the person.

53. Jogging on hard surfaces with insufficiently padded shoes produces large forces in the feet and legs. (a) Calculate the magnitude of the force needed to stop the downward motion of a jogger's leg, if his leg has a mass of 13.0 kg, a speed of 6.00 m/s, and stops in a distance of 1.50 cm. (Be certain to include the weight of the 75.0-kg jogger's body.) (b) Compare this force with the weight of the jogger.

54. (a) Calculate the energy in kJ used by a 55.0-kg woman who does 50 deep knee bends in which her center of mass is lowered and raised 0.400 m. (She does work in both directions.) You may assume her efficiency is 20%. (b) What is the average power consumption rate in watts if she does this in 3.00 min?

55. Kanellos Kanellopoulos flew 119 km from Crete to Santorini, Greece, on April 23, 1988, in the *Daedalus 88*, an aircraft powered by a bicycle-type drive mechanism (see **Figure 7.43**). His useful power output for the 234-min trip was about 350 W. Using the efficiency for cycling from **Table 7.2**, calculate the food energy in kilojoules he metabolized during the flight.

Figure 7.43 The Daedalus 88 in flight. (credit: NASA photo by Beasley)

56. The swimmer shown in **Figure 7.44** exerts an average horizontal backward force of 80.0 N with his arm during each 1.80 m long stroke. (a) What is his work output in each stroke? (b) Calculate the power output of his arms if he does 120 strokes per minute.

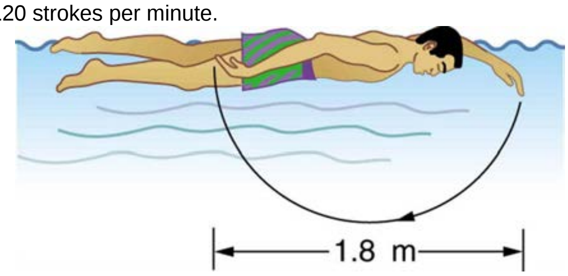


Figure 7.44

57. Mountain climbers carry bottled oxygen when at very high altitudes. (a) Assuming that a mountain climber uses oxygen at twice the rate for climbing 116 stairs per minute (because of low air temperature and winds), calculate how many liters of oxygen a climber would need for 10.0 h of climbing. (These are liters at sea level.) Note that only 40% of the inhaled oxygen is utilized; the rest is exhaled. (b) How much useful work does the climber do if he and his equipment have a mass of 90.0 kg and he gains 1000 m of altitude? (c) What is his efficiency for the 10.0-h climb?

58. The awe-inspiring Great Pyramid of Cheops was built more than 4500 years ago. Its square base, originally 230 m on a side, covered 13.1 acres, and it was 146 m high, with a mass of about $7\times10^9\text{ kg}$. (The pyramid's dimensions are slightly different today due to quarrying and some sagging.) Historians estimate that 20,000 workers spent 20 years to construct it, working 12-hour days, 330 days per year. (a) Calculate the gravitational potential energy stored in the pyramid, given its center of mass is at one-fourth its height. (b) Only a fraction of the workers lifted blocks; most were involved in support services such as building ramps (see **Figure 7.45**), bringing food and water, and hauling blocks to the site. Calculate the efficiency of the workers who did the lifting, assuming there were 1000 of them and they consumed food energy at the rate of 300 kcal/h. What does your answer imply about how much of their work went into block-lifting, versus how much work went into friction and lifting and lowering their own bodies? (c) Calculate the mass of food that had to be supplied each day, assuming that the average worker required 3600 kcal per day and that their diet was 5% protein, 60% carbohydrate, and 35% fat. (These proportions neglect the mass of bulk and nondigestible materials consumed.)

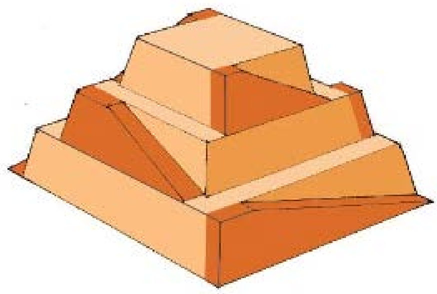


Figure 7.45 Ancient pyramids were probably constructed using ramps as simple machines. (credit: Franck Monnier, Wikimedia Commons)

59. (a) How long can you play tennis on the 800 kJ (about 200 kcal) of energy in a candy bar? (b) Does this seem like a long time? Discuss why exercise is necessary but may not be sufficient to cause a person to lose weight.

7.9 World Energy Use

60. Integrated Concepts

(a) Calculate the force the woman in **Figure 7.46** exerts to do a push-up at constant speed, taking all data to be known to three digits. (b) How much work does she do if her center of mass rises 0.240 m? (c) What is her useful power output if she does 25 push-ups in 1 min? (Should work done lowering her body be included? See the discussion of useful work in **Work, Energy, and Power in Humans**.

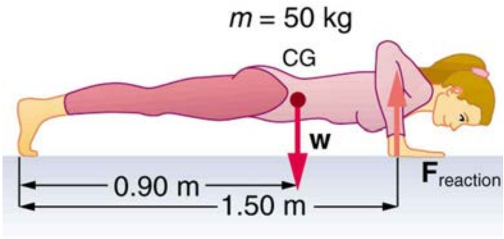


Figure 7.46 Forces involved in doing push-ups. The woman's weight acts as a force exerted downward on her center of gravity (CG).

61. Integrated Concepts

A 75.0-kg cross-country skier is climbing a 3.0° slope at a constant speed of 2.00 m/s and encounters air resistance of 25.0 N. Find his power output for work done against the gravitational force and air resistance. (b) What average force does he exert backward on the snow to accomplish this? (c) If he continues to exert this force and to experience the same air resistance when he reaches a level area, how long will it take him to reach a velocity of 10.0 m/s?

62. Integrated Concepts

The 70.0-kg swimmer in **Figure 7.44** starts a race with an initial velocity of 1.25 m/s and exerts an average force of 80.0 N backward with his arms during each 1.80 m long stroke. (a) What is his initial acceleration if water resistance is 45.0 N? (b) What is the subsequent average resistance force from the water during the 5.00 s it takes him to reach his top velocity of 2.50 m/s? (c) Discuss whether water resistance seems to increase linearly with velocity.

63. Integrated Concepts

A toy gun uses a spring with a force constant of 300 N/m to propel a 10.0-g steel ball. If the spring is compressed 7.00 cm and friction is negligible: (a) How much force is needed to compress the spring? (b) To what maximum height can the ball be shot? (c) At what angles above the horizontal may a child aim to hit a target 3.00 m away at the same height as the gun? (d) What is the gun's maximum range on level ground?

64. Integrated Concepts

(a) What force must be supplied by an elevator cable to produce an acceleration of $0.800\ \text{m/s}^2$ against a 200-N frictional force, if the mass of the loaded elevator is 1500 kg? (b) How much work is done by the cable in lifting the elevator 20.0 m? (c) What is the final speed of the elevator if it starts from rest? (d) How much work went into thermal energy?

65. Unreasonable Results

A car advertisement claims that its 900-kg car accelerated from rest to 30.0 m/s and drove 100 km, gaining 3.00 km in altitude, on 1.0 gal of gasoline. The average force of friction including air resistance was 700 N. Assume all values are known to three significant figures. (a) Calculate the car's efficiency. (b) What is unreasonable about the result? (c) Which premise is unreasonable, or which premises are inconsistent?

66. Unreasonable Results

Body fat is metabolized, supplying 9.30 kcal/g, when dietary intake is less than needed to fuel metabolism. The manufacturers of an exercise bicycle claim that you can lose 0.500 kg of fat per day by vigorously exercising for 2.00 h per day on their machine. (a) How many kcal are supplied by the metabolization of 0.500 kg of fat? (b) Calculate the kcal/min that you would have to utilize to metabolize fat at the rate of 0.500 kg in 2.00 h. (c) What is unreasonable about the results? (d) Which premise is unreasonable, or which premises are inconsistent?

67. Construct Your Own Problem

Consider a person climbing and descending stairs. Construct a problem in which you calculate the long-term rate at which stairs can be climbed considering the mass of the person, his ability to generate power with his legs, and the height of a single stair step. Also consider why the same person can descend stairs at a faster rate for a nearly unlimited time in spite of the fact that very similar forces are exerted going down as going up. (This points to a fundamentally different process for descending versus climbing stairs.)

68. Construct Your Own Problem

Consider humans generating electricity by pedaling a device similar to a stationary bicycle. Construct a problem in which you determine the number of people it would take to replace a large electrical generation facility. Among the things to consider are the power output that is reasonable using the legs, rest time, and the need for electricity 24 hours per day. Discuss the practical implications of your results.

69. Integrated Concepts

A 105-kg basketball player crouches down 0.400 m while waiting to jump. After exerting a force on the floor through this 0.400 m, his feet leave the floor and his center of gravity rises 0.950 m above its normal standing erect position. (a) Using energy considerations, calculate his velocity when he leaves the floor. (b) What average force did he exert on the floor? (Do not neglect the force to support his weight as well as that to accelerate him.) (c) What was his power output during the acceleration phase?

Test Prep for AP® Courses

7.1 Work: The Scientific Definition

1. Given Table 7.7 about how much force does the rocket engine exert on the 3.0-kg payload?

Table 7.7

Distance traveled with rocket engine firing (m)	Payload final velocity (m/s)
500	310
490	300
1020	450
505	312

a. 150 N
b. 300 N
c. 450 N
d. 600 N

2. You have a cart track, a cart, several masses, and a position-sensing pulley. Design an experiment to examine how the force exerted on the cart does work as it moves through a distance.

3. Look at Figure 7.10(c). You compress a spring by *x*, and then release it. Next you compress the spring by 2*x*. How much more work did you do the second time than the first?
a. Half as much
b. The same
c. Twice as much
d. Four times as much

4. You have a cart track, two carts, several masses, a position-sensing pulley, and a piece of carpet (a rough surface) that will fit over the track. Design an experiment to examine how the force exerted on the cart does work as the cart moves through a distance.

5. A crane is lifting construction materials from the ground to an elevation of 60 m. Over the first 10 m, the motor linearly increases the force it exerts from 0 to 10 kN. It exerts that constant force for the next 40 m, and then winds down to 0 N again over the last 10 m, as shown in the figure. What is the total work done on the construction materials?

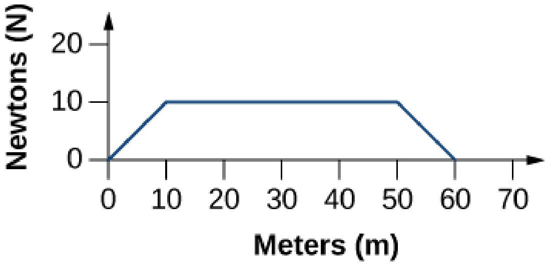


Figure 7.47

a. 500 kJ
b. 600 kJ
c. 300 kJ
d. 18 MJ

7.2 Kinetic Energy and the Work-Energy Theorem

6. A toy car is going around a loop-the-loop. Gravity ____ the kinetic energy on the upward side of the loop, ____ the kinetic energy at the top, and ____ the kinetic energy on the downward side of the loop.
a. increases, decreases, has no effect on
b. decreases, has no effect on, increases
c. increases, has no effect on, decreases
d. decreases, increases, has no effect on

7. A roller coaster is set up with a track in the form of a perfect cosine. Describe and graph what happens to the kinetic energy of a cart as it goes through the first full period of the track.

8. If wind is blowing horizontally toward a car with an angle of 30 degrees from the direction of travel, the kinetic energy will ____. If the wind is blowing at a car at 135 degrees from the direction of travel, the kinetic energy will ____.
a. increase, increase
b. increase, decrease
c. decrease, increase
d. decrease, decrease

9. In what direction relative to the direction of travel can a force act on a car (traveling on level ground), and not change the kinetic energy? Can you give examples of such forces?

10. A 2000-kg airplane is coming in for a landing, with a velocity 5 degrees below the horizontal and a drag force of 40 kN acting directly rearward. Kinetic energy will ____ due to the net force of ____.
a. increase, 20 kN
b. decrease, 40 kN
c. increase, 45 kN
d. decrease, 45 kN

11. You are participating in the Iditarod, and your sled dogs are pulling you across a frozen lake with a force of 1200 N while a 300 N wind is blowing at you at 135 degrees from your direction of travel. What is the net force, and will your kinetic energy increase or decrease?

12. A model drag car is being accelerated along its track from rest by a motor with a force of 75 N, but there is a drag force of 30 N due to the track. What is the kinetic energy after 2 m of travel?
a. 90 J
b. 150 J
c. 210 J
d. 60 J

13. You are launching a 2-kg potato out of a potato cannon. The cannon is 1.5 m long and is aimed 30 degrees above the horizontal. It exerts a 50 N force on the potato. What is the kinetic energy of the potato as it leaves the muzzle of the potato cannon?

14. When the force acting on an object is parallel to the direction of the motion of the center of mass, the mechanical energy ____. When the force acting on an object is antiparallel to the direction of the center of mass, the mechanical energy ____.
a. increases, increases
b. increases, decreases
c. decreases, increases
d. decreases, decreases

15. Describe a system in which the main forces acting are parallel or antiparallel to the center of mass, and justify your answer.

16. A child is pulling two red wagons, with the second one tied to the first by a (non-stretching) rope. Each wagon has a mass of 10 kg. If the child exerts a force of 30 N for 5.0 m, how much has the kinetic energy of the two-wagon system changed?

a. 300 J
b. 150 J
c. 75 J
d. 60 J

17. A child has two red wagons, with the rear one tied to the front by a (non-stretching) rope. If the child pushes on the rear wagon, what happens to the kinetic energy of each of the wagons, and the two-wagon system?

18. Draw a graph of the force parallel to displacement exerted on a stunt motorcycle going through a loop-the-loop versus the distance traveled around the loop. Explain the net change in energy.

7.3 Gravitational Potential Energy

19. A 1.0 kg baseball is flying at 10 m/s. How much kinetic energy does it have? Potential energy?

a. 10 J, 20 J
b. 50 J, 20 J
c. unknown, 50 J
d. 50 J, unknown

20. A 2.0-kg potato has been launched out of a potato cannon at 9.0 m/s. What is the kinetic energy? If you then learn that it is 4.0 m above the ground, what is the total mechanical energy relative to the ground?

a. 78 J, 3 J
b. 160 J, 81 J
c. 81 J, 160 J
d. 81 J, 3 J

21. You have a 120-g yo-yo that you are swinging at 0.9 m/s. How much energy does it have? How high can it get above the lowest point of the swing without your doing any additional work, on Earth? How high could it get on the Moon, where gravity is 1/6 Earth's?

7.4 Conservative Forces and Potential Energy

22. Two 4.0 kg masses are connected to each other by a spring with a force constant of 25 N/m and a rest length of 1.0 m. If the spring has been compressed to 0.80 m in length and the masses are traveling toward each other at 0.50 m/s (each), what is the total energy in the system?

a. 1.0 J
b. 1.5 J
c. 9.0 J
d. 8.0 J

23. A spring with a force constant of 5000 N/m and a rest length of 3.0 m is used in a catapult. When compressed to 1.0 m, it is used to launch a 50 kg rock. However, there is an error in the release mechanism, so the rock gets launched almost straight up. How high does it go, and how fast is it going when it hits the ground?

24. What information do you need to calculate the kinetic energy and potential energy of a spring? Potential energy due to gravity? How many objects do you need information about for each of these cases?

25. You are loading a toy dart gun, which has two settings, the more powerful with the spring compressed twice as far as the lower setting. If it takes 5.0 J of work to compress the dart gun to the lower setting, how much work does it take for the higher setting?

a. 20 J
b. 10 J
c. 2.5 J
d. 40 J

26. Describe a system you use daily with internal potential energy.

27. Old-fashioned pendulum clocks are powered by masses that need to be wound back to the top of the clock about once a week to counteract energy lost due to friction and to the chimes. One particular clock has three masses: 4.0 kg, 4.0 kg, and 6.0 kg. They can drop 1.3 meters. How much energy does the clock use in a week?

a. 51 J
b. 76 J
c. 127 J
d. 178 J

28. A water tower stores not only water, but (at least part of) the energy to move the water. How much? Make reasonable estimates for how much water is in the tower, and other quantities you need.

29. Old-fashioned pocket watches needed to be wound daily so they wouldn't run down and lose time, due to the friction in the internal components. This required a large number of turns of the winding key, but not much force per turn, and it was possible to overwind and break the watch. How was the energy stored?

a. A small mass raised a long distance
b. A large mass raised a short distance
c. A weak spring deformed a long way
d. A strong spring deformed a short way

30. Some of the very first clocks invented in China were powered by water. Describe how you think this was done.

7.5 Nonconservative Forces

31. You are in a room in a basement with a smooth concrete floor (friction force equals 40 N) and a nice rug (friction force equals 55 N) that is 3 m by 4 m. However, you have to push a very heavy box from one corner of the rug to the opposite corner of the rug. Will you do more work against friction going around the floor or across the rug, and how much extra?

a. Across the rug is 275 J extra
b. Around the floor is 5 J extra
c. Across the rug is 5 J extra
d. Around the floor is 280 J extra

32. In the Appalachians, along the interstate, there are ramps of loose gravel for semis that have had their brakes fail to drive into to stop. Design an experiment to measure how effective this would be.

7.6 Conservation of Energy

33. You do 30 J of work to load a toy dart gun. However, the dart is 10 cm long and feels a frictional force of 10 N while going through the dart gun's barrel. What is the kinetic energy of the fired dart?

a. 30 J
b. 29 J
c. 28 J
d. 27 J

34. When an object is lifted by a crane, it begins and ends its motion at rest. The same is true of an object pushed across a rough surface. Explain why this happens. What are the differences between these systems?

35. A child has two red wagons, with the rear one tied to the front by a stretchy rope (a spring). If the child pulls on the front wagon, the ____ increases.

a. kinetic energy of the wagons
b. potential energy stored in the spring
c. both A and B
d. not enough information

36. A child has two red wagons, with the rear one tied to the front by a stretchy rope (a spring). If the child pulls on the front wagon, the energy stored in the system increases. How do the relative amounts of potential and kinetic energy in this system change over time?

37. Which of the following are closed systems?

a. Earth
b. a car
c. a frictionless pendulum
d. a mass on a spring in a vacuum

38. Describe a real-world example of a closed system.

39. A 5.0-kg rock falls off of a 10 m cliff. If air resistance exerts a force of 10 N, what is the kinetic energy when the rock hits the ground?

a. 400 J
b. 12.6 m/s
c. 100 J
d. 500 J

40. Hydroelectricity is generated by storing water behind a dam, and then letting some of it run through generators in the dam to turn them. If the system is the water, what is the environment that is doing work on it? If a dam has water 100 m deep behind it, how much energy was generated if 10,000 kg of water exited the dam at 2.0 m/s?

41. Before railroads were invented, goods often traveled along canals, with mules pulling barges from the bank. If a mule is exerting a 1200 N force for 10 km, and the rope connecting the mule to the barge is at a 20 degree angle from the direction of travel, how much work did the mule do on the barge?

a. 12 MJ
b. 11 MJ
c. 4.1 MJ
d. 6 MJ

42. Describe an instance today in which you did work, by the scientific definition. Then calculate how much work you did in that instance, showing your work.

Chapter 7

Problems & Exercises

1

$3.00\text{ J} = 7.17\times10^{-4}\text{ kcal}$

3

(a) $5.92\times10^{5}\text{ J}$

(b) $-5.88\times10^{5}\text{ J}$

(c) The net force is zero.

5

$3.14\times10^{3}\text{ J}$

7

(a) -700 J

(b) 0

(c) 700 J

(d) 38.6 N

(e) 0

9

$1/250$

11

$1.1\times10^{10}\text{ J}$

13

$2.8\times10^{3}\text{ N}$

15

102 N

16

(a) $1.96\times10^{16}\text{ J}$

(b) The ratio of gravitational potential energy in the lake to the energy stored in the bomb is 0.52. That is, the energy stored in the lake is approximately half that in a 9-megaton fusion bomb.

18

(a) 1.8 J

(b) 8.6 J

20

$v_f = \sqrt{2gh + v_0^{\,2}} = \sqrt{2(9.80\text{ m/s}^2)(-0.180\text{ m}) + (2.00\text{ m/s})^2} = 0.687\text{ m/s}$

22

$7.81\times10^{5}\text{ N/m}$

24

9.46 m/s

26

4×10^{4} molecules

27

Equating ΔPE_g and ΔKE, we obtain $v = \sqrt{2gh + v_0^{\,2}} = \sqrt{2(9.80\text{ m/s}^2)(20.0\text{ m}) + (15.0\text{ m/s})^2} = 24.8\text{ m/s}$

29

(a) 25×10^{6} years

(b) This is much, much longer than human time scales.

30

2×10^{-10}

32

(a) 40

(b) 8 million

34

$149

36

(a) 208 W

(b) 141 s

38

(a) 3.20 s

(b) 4.04 s

40

(a) $9.46 \times 10^7 \text{ J}$

(b) 2.54 y

42

Identify knowns: $m = 950 \text{ kg}$, slope angle $\theta = 2.00°$, $v = 3.00 \text{ m/s}$, $f = 600 \text{ N}$

Identify unknowns: power P of the car, force F that car applies to road

Solve for unknown:

$$P = \frac{W}{t} = \frac{Fd}{t} = F\left(\frac{d}{t}\right) = Fv,$$

where F is parallel to the incline and must oppose the resistive forces and the force of gravity:

$$F = f + w = 600 \text{ N} + mg \sin \theta$$

Insert this into the expression for power and solve:

$$\begin{aligned} P &= (f + mg \sin \theta)v \\ &= \left[600 \text{ N} + (950 \text{ kg})(9.80 \text{ m/s}^2)\sin 2°\right](30.0 \text{ m/s}) \\ &= 2.77 \times 10^4 \text{ W} \end{aligned}$$

About 28 kW (or about 37 hp) is reasonable for a car to climb a gentle incline.

44

(a) 9.5 min

(b) 69 flights of stairs

46

641 W, 0.860 hp

48

31 g

50

14.3%

52

(a) $3.21 \times 10^4 \text{ N}$

(b) $2.35 \times 10^3 \text{ N}$

(c) Ratio of net force to weight of person is 41.0 in part (a); 3.00 in part (b)

54

(a) 108 kJ

(b) 599 W

56

(a) 144 J

(b) 288 W

58

(a) 2.50×10^{12} J

(b) 2.52%

(c) 1.4×10^{4} kg (14 metric tons)

60

(a) 294 N

(b) 118 J

(c) 49.0 W

62

(a) 0.500 m/s^2

(b) 62.5 N

(c) Assuming the acceleration of the swimmer decreases linearly with time over the 5.00 s interval, the frictional force must therefore be increasing linearly with time, since $f = F - ma$. If the acceleration decreases linearly with time, the velocity will contain a term dependent on time squared (t^2). Therefore, the water resistance will not depend linearly on the velocity.

64

(a) 16.1×10^{3} N

(b) 3.22×10^{5} J

(c) 5.66 m/s

(d) 4.00 kJ

66

(a) 4.65×10^{3} kcal

(b) 38.8 kcal/min

(c) This power output is higher than the highest value on **Table 7.5**, which is about 35 kcal/min (corresponding to 2415 watts) for sprinting.

(d) It would be impossible to maintain this power output for 2 hours (imagine sprinting for 2 hours!).

69

(a) 4.32 m/s

(b) 3.47×10^{3} N

(c) 8.93 kW

Test Prep for AP® Courses

1
(b)
3
(d)
5
(a)
7
The kinetic energy should change in the form of –cos, with an initial value of 0 or slightly above, and ending at the same level.
9
Any force acting perpendicular will have no effect on kinetic energy. Obvious examples are gravity and the normal

force, but others include wind directly from the side and rain or other precipitation falling straight down.

11

Note that the wind is pushing from behind and one side, so your KE will increase. The net force has components of 1400 N in the direction of travel and 212 N perpendicular to the direction of travel. So the net force is 1420 N at 8.5 degrees from the direction of travel.

13

Gravity has a component perpendicular to the cannon (and to displacement, so it is irrelevant) and has a component parallel to the cannon. The latter is equal to 9.8 N. Thus the net force in the direction of the displacement is 50 N − 9.8 N, and the kinetic energy is 60 J.

15

The potato cannon (and many other projectile launchers) above is an option, with a force launching the projectile, friction, potentially gravity depending on the direction it is pointed, etc. A drag (or other) car accelerating is another possibility.

17

The kinetic energy of the rear wagon increases. The front wagon does not, until the rear wagon collides with it. The total system may be treated by its center of mass, halfway between the wagons, and its energy increases by the same amount as the sum of the two individual wagons.

19

(d)

21

0.049 J; 0.041 m, 0.25 m

23

20 m high, 20 m/s.

25

(a)

27

(d)

29

(c)

31

(b)

33

(c)

35

(c)

37

(c), (d)

39

(a)

41

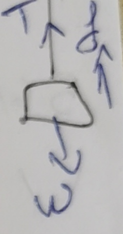
(b)

Chapter 8

Work And Energy Problems Solved

~~3/a/ $W_{net} = F_{net} . d = (F - f) . d = (W - f) d = ...$~~

3/a/ $W_{cable} = \cancel{F}\, T . d = (W + f) . d = 592000\,J$



b/ $W_g = W . d = -588000\,J$

c/ constant speed $\to a = \to F_{net} = 0 \to W_{net} = 0$

5/ $W_{onBox} = F . d = 500 . 4 = 2000\,N$

$W_{onBody} = W_x . d = W \sin(20) . d = 1139$

$W = W_{onBox} + W_{onBody} = 3139{,}6\,J$

13/ $F_{net} = m . a$; $a = \dfrac{\cancel{V_f}^2 - V_i^2}{2 \Delta x} = 3.025\,m/s^2$ ($V_f = 0$)

$\to F = m . a = 2722.5\,N.$

27/ $m . g h + \frac{1}{2} m V^2 = cst \to \Delta PE = \Delta KE$

$\to \cancel{m} g h = \frac{1}{2} \cancel{m} (V_f^2 - V_i^2)$

$\to V_f = \sqrt{2 g h + V_i^2} = 24.8\,m/s$

36/a/ $P = \dfrac{W}{t} = \dfrac{6.10^6}{8 . 3600} = 208.3\,W$

b/ $t = \dfrac{W}{P} = \dfrac{m . g h}{P} = 141\,s$

46/ ~~...~~ $P = \frac{W}{t} = \frac{F.d}{t} = \frac{m.ad}{t}$

$a = \frac{14}{1.2} = 11.67 \, m/s^2$

~~...~~ $\Delta x = \frac{1}{2}(v_f + \cancel{v_i}^{=0})t \rightarrow t = \frac{2\Delta x}{}$

$\rightarrow P =$

56/a/ $W = F.d = 144 \, J.$

b/ $\frac{120}{60} = 2$ strokes/second

$\rightarrow$ ~~...~~ $P = 2W = 288 \, J.$

60/a/ $F = W.0.6 = m.g.0.6 = 294 \, N$

b/ $W = w.d = m.g.d = 118 \, J$

c/ ~~...~~ $\frac{25}{60} = 0.42$ pushup/second

$P = 0.42 \cdot 118 = 49 \, W$

Test Prep:

1/ $F = ma$; $a = \frac{v_f^2 - \cancel{v_i^2}^{=0}}{2\Delta y} \simeq 100 \, m/s^2$

$F = 300 \, N.$

~~...~~ 5/ $\boxed{a}$: Area under the graph: W.

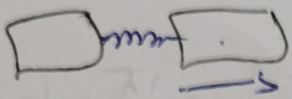
19 $\boxed{d}$ $KE = \frac{1}{2}mv^2$

PE: unknown

21/ $KE = \frac{1}{2}mU^2 = 0.049\,J$

$KE = PE \rightarrow mgh = KE \rightarrow h = \frac{KE}{m \cdot g} = 0.041\,m$

$h = \frac{KE \cdot 6}{m \cdot g} = 0.25\,m.$

35/  $\boxed{c}$

37/ c, d

~~$\Delta PE = \Delta KE$~~

$\rightarrow \cancel{mgh = \frac{1}{2}\frac{mv^2}{6}}$ (v, ~~[illegible]~~)

39/ $F = m \cdot g - f = 5 \cdot 9.8 - 10 = 39$

$W = F \cdot d = 390\,J = \Delta KE$

$KE_i = 0\,J \rightarrow KE_f = W = 390\,J \simeq 400\,J$ (for $g = 10\,\frac{m}{s^2}$)