

GLOBAL  
EDITION



# University Physics

## *Volume 1*

Fifteenth Edition in SI Units

Hugh D. Young • Roger A. Freedman



# BRIEF CONTENTS

---

## MECHANICS

---

1	Units, Physical Quantities, and Vectors	29
2	Motion Along a Straight Line	62
3	Motion in Two or Three Dimensions	94
4	Newton's Laws of Motion	128
5	Applying Newton's Laws	157
6	Work and Kinetic Energy	199
7	Potential Energy and Energy Conservation	229
8	Momentum, Impulse, and Collisions	263
9	Rotation of Rigid Bodies	300
10	Dynamics of Rotational Motion	330
11	Equilibrium and Elasticity	365
12	Fluid Mechanics	394
13	Gravitation	423
14	Periodic Motion	457

## WAVES/ACOUSTICS

---

15	Mechanical Waves	492
16	Sound and Hearing	529

## THERMODYNAMICS

---

17	Temperature and Heat	569
18	Thermal Properties of Matter	607
19	The First Law of Thermodynamics	641
20	The Second Law of Thermodynamics	670

## ELECTROMAGNETISM

---

21	Electric Charge and Electric Field	706
22	Gauss's Law	746
23	Electric Potential	775
24	Capacitance and Dielectrics	809
25	Current, Resistance, and Electromotive Force	840
26	Direct-Current Circuits	872

27	Magnetic Field and Magnetic Forces	906
28	Sources of Magnetic Field	946
29	Electromagnetic Induction	981
30	Inductance	1016
31	Alternating Current	1046
32	Electromagnetic Waves	1076

## OPTICS

---

33	The Nature and Propagation of Light	1105
34	Geometric Optics	1138
35	Interference	1187
36	Diffraction	1213

## MODERN PHYSICS

---

37	Relativity	1245
38	Photons: Light Waves Behaving as Particles	1281
39	Particles Behaving as Waves	1306
40	Quantum Mechanics I: Wave Functions	1348
41	Quantum Mechanics II: Atomic Structure	1387
42	Molecules and Condensed Matter	1434
43	Nuclear Physics	1467
44	Particle Physics and Cosmology	1508

## APPENDICES

---

A	The International System of Units	A-1
B	Unit Conversion Factors	A-3
C	The British System of Units	A-3
D	Useful Mathematical Relations	A-6
E	The Greek Alphabet	A-7
F	Periodic Table of the Elements	A-8
G	Numerical Constants	A-9
	Answers to Odd-Numbered Problems	A-11
	Credits	C-1
	Index	I-1

## BRIDGING PROBLEM A Spring That Disobeys Hooke's Law

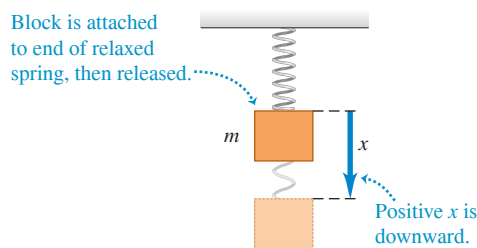
Consider a hanging spring of negligible mass that does *not* obey Hooke's law. When the spring is pulled downward by a distance  $x$ , the spring exerts an upward force of magnitude  $\alpha x^2$ , where  $\alpha$  is a positive constant. Initially the hanging spring is relaxed (not extended). We then attach a block of mass  $m$  to the spring and release the block. The block stretches the spring as it falls (**Fig. 6.28**). (a) How fast is the block moving when it has fallen a distance  $x_1$ ? (b) At what rate does the spring do work on the block at this point? (c) Find the maximum distance  $x_2$  that the spring stretches. (d) Will the block *remain* at the point found in part (c)?

### SOLUTION GUIDE

#### IDENTIFY and SET UP

1. The spring force in this problem isn't constant, so you have to use the work–energy theorem. You'll also need Eq. (6.7) to find the work done by the spring over a given displacement.
2. Draw a free-body diagram for the block, including your choice of coordinate axes. Note that  $x$  represents how far the spring is *stretched*, so choose the positive  $x$ -direction to be downward, as in Fig. 6.28. On your coordinate axis, label the points  $x = x_1$  and  $x = x_2$ .

Figure 6.28 The block is attached to a spring that does not obey Hooke's law.



3. Make a list of the unknown quantities, and decide which of these are the target variables.

#### EXECUTE

4. Calculate the work done on the block by the spring as the block falls an arbitrary distance  $x$ . (The integral isn't a difficult one. Use Appendix D if you need a reminder.) Is the work done by the spring positive, negative, or zero?
5. Calculate the work done on the block by any other forces as the block falls an arbitrary distance  $x$ . Is this work positive, negative, or zero?
6. Use the work–energy theorem to find the target variables. (You'll also need an equation for power.) *Hint:* When the spring is at its maximum stretch, what is the speed of the block?
7. To answer part (d), consider the *net* force that acts on the block when it is at the point found in part (c).

#### EVALUATE

8. We learned in Section 2.5 that after an object dropped from rest has fallen freely a distance  $x_1$ , its speed is  $\sqrt{2gx_1}$ . Use this to decide whether your answer in part (a) makes sense. In addition, ask yourself whether the algebraic sign of your answer in part (b) makes sense.
9. Find the value of  $x$  where the net force on the block would be zero. How does this compare to your result for  $x_2$ ? Is this consistent with your answer in part (d)?

## PROBLEMS

•, ••, •••: Difficulty levels. **CP**: Cumulative problems incorporating material from earlier chapters. **CALC**: Problems requiring calculus. **DATA**: Problems involving real data, scientific evidence, experimental design, and/or statistical reasoning. **BIO**: Biosciences problems.

### DISCUSSION QUESTIONS

**Q6.1** The sign of many physical quantities depends on the choice of coordinates. For example,  $a_y$  for free-fall motion can be negative or positive, depending on whether we choose upward or downward as positive. Is the same true of work? In other words, can we make positive work negative by a different choice of coordinates? Explain.

**Q6.2** A lift is hoisted by its cables at constant speed. Is the total work done on the lift positive, negative, or zero? Explain.

**Q6.3** A rope tied to an object is pulled, causing the object to accelerate. But according to Newton's third law, the object pulls back on the rope with a force of equal magnitude and opposite direction. Is the total work done then zero? If so, how can the object's kinetic energy change? Explain.

**Q6.4** If it takes total work  $W$  to give an object a speed  $v$  and kinetic energy  $K$ , starting from rest, what will be the object's speed (in terms of  $v$ ) and kinetic energy (in terms of  $K$ ) if we do twice as much work on it, again starting from rest?

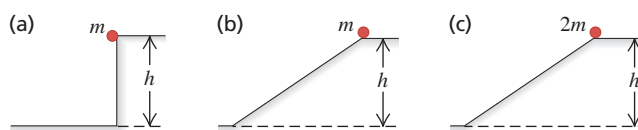
**Q6.5** If there is a net nonzero force on a moving object, can the total work done on the object be zero? Explain, using an example.

**Q6.6** In Example 5.5 (Section 5.1), how does the work done on the bucket by the tension in the cable compare with the work done on the cart by the tension in the cable?

**Q6.7** In the conical pendulum of Example 5.20 (Section 5.4), which of the forces do work on the bob while it is swinging?

**Q6.8** For the cases shown in **Fig. Q6.8**, the object is released from rest at the top and feels no friction or air resistance. In which (if any) cases will the mass have (i) the greatest speed at the bottom and (ii) the most work done on it by the time it reaches the bottom?

Figure Q6.8



**Q6.9** A force  $\vec{F}$  is in the  $x$ -direction and has a magnitude that depends on  $x$ . Sketch a possible graph of  $F$  versus  $x$  such that the force does zero work on an object that moves from  $x_1$  to  $x_2$ , even though the force magnitude is not zero at all  $x$  in this range.

**Q6.10** Does a car's kinetic energy change more when the car speeds up from 10 to 15 m/s or from 15 to 20 m/s? Explain.

**Q6.11** A falling brick has a mass of 1.5 kg and is moving straight downward with a speed of 5.0 m/s. A 1.5 kg physics book is sliding across the floor with a speed of 5.0 m/s. A 1.5 kg melon is traveling with a horizontal velocity component 3.0 m/s to the right and a vertical component 4.0 m/s upward. Do all of these objects have the same velocity? Do all of them have the same kinetic energy? For both questions, give your reasoning.

**Q6.12** Can the *total* work done on an object during a displacement be negative? Explain. If the total work is negative, can its magnitude be larger than the initial kinetic energy of the object? Explain.

**Q6.13** A net force acts on an object and accelerates it from rest to a speed  $v_1$ . In doing so, the force does an amount of work  $W_1$ . By what factor must the work done on the object be increased to produce three times the final speed, with the object again starting from rest?

**Q6.14** A truck speeding down the motorway has a lot of kinetic energy relative to a stopped traffic officer but no kinetic energy relative to the truck driver. In these two frames of reference, is the same amount of work required to stop the truck? Explain.

**Q6.15** You are holding a briefcase by the handle, with your arm straight down by your side. Does the force your hand exerts do work on the briefcase when (a) you walk at a constant speed down a horizontal hallway and (b) you ride a lift from the first to second floor of a building? In both cases justify your answer.

**Q6.16** When a book slides along a tabletop, the force of friction does negative work on it. Can friction ever do *positive* work? Explain. (*Hint*: Think of a box in the back of an accelerating truck.)

**Q6.17** Time yourself while running up a flight of steps, and compute the average rate at which you do work against the force of gravity.

**Q6.18 Fractured Physics.** Many terms from physics are badly misused in everyday language. In both cases, explain the errors involved. (a) A *strong* person is called *powerful*. What is wrong with this use of *power*? (b) When a worker carries a bag of concrete along a level construction site, people say he did a lot of *work*. Did he?

**Q6.19** An advertisement for a portable electrical generating unit claims that the unit's diesel engine produces 20 MW to drive an electrical generator that produces 30 MW of electrical power. Is this possible? Explain.

**Q6.20** A car speeds up while the engine delivers constant power. Is the acceleration greater at the beginning of this process or at the end? Explain.

**Q6.21** Consider a graph of instantaneous power versus time, with the vertical  $P$ -axis starting at  $P = 0$ . What is the physical significance of the area under the  $P$ -versus- $t$  curve between vertical lines at  $t_1$  and  $t_2$ ? How could you find the average power from the graph? Draw a  $P$ -versus- $t$  curve that consists of two straight-line sections and for which the peak power is equal to twice the average power.

**Q6.22** A nonzero net force acts on an object. Is it possible for any of the following quantities to be constant: the object's (a) speed; (b) velocity; (c) kinetic energy?

**Q6.23** When a certain force is applied to an ideal spring, the spring stretches a distance  $x$  from its unstretched length and does work  $W$ . If instead twice the force is applied, what distance (in terms of  $x$ ) does the spring stretch from its unstretched length, and how much work (in terms of  $W$ ) is required to stretch it this distance?

**Q6.24** If work  $W$  is required to stretch an ideal spring a distance  $x$  from its unstretched length, what work (in terms of  $W$ ) is required to stretch the spring an *additional* distance  $x$ ?

## EXERCISES

### Section 6.1 Work

**6.1** • You push your physics book 1.10 m along a horizontal tabletop with a horizontal push of 3.00 N while the opposing force of friction is 0.700 N. How much work does each of the following forces do on the book: (a) your 3.00-N push, (b) the friction force, (c) the normal force from the tabletop, and (d) gravity? (e) What is the net work done on the book?

**6.2** • Using a cable with a tension of 1350 N, a tow truck pulls a car 5.00 km along a horizontal roadway. (a) How much work does the cable do on the car if it pulls horizontally? If it pulls at  $35.0^\circ$  above the horizontal? (b) How much work does the cable do on the tow truck in both cases of part (a)? (c) How much work does gravity do on the car in part (a)?

**6.3** • A factory worker pushes a 30.0 kg crate a distance of 4.5 m along a level floor at constant velocity by pushing horizontally on it. The coefficient of kinetic friction between the crate and the floor is 0.25. (a) What magnitude of force must the worker apply? (b) How much work is done on the crate by this force? (c) How much work is done on the crate by friction? (d) How much work is done on the crate by the normal force? By gravity? (e) What is the total work done on the crate?

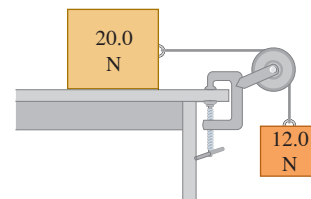
**6.4** • Suppose the worker in Exercise 6.3 pushes downward at an angle of  $30^\circ$  below the horizontal. (a) What magnitude of force must the worker apply to move the crate at constant velocity? (b) How much work is done on the crate by this force when the crate is pushed a distance of 4.5 m? (c) How much work is done on the crate by friction during this displacement? (d) How much work is done on the crate by the normal force? By gravity? (e) What is the total work done on the crate?

**6.5** • A 73.0 kg painter climbs a ladder that is 2.70 m long and leans against a vertical wall. The ladder makes a  $25.0^\circ$  angle with the wall. (a) How much work does gravity do on the painter? (b) Does the answer to part (a) depend on whether the painter climbs at constant speed or accelerates up the ladder?

**6.6** • Two tugboats pull a disabled supertanker. Each tug exerts a constant force of  $1.80 \times 10^6$  N, one  $16^\circ$  west of north and the other  $14^\circ$  east of north, as they pull the tanker 0.63 km toward the north. What is the total work they do on the supertanker?

**6.7** • Two blocks are connected Figure E6.7

by a very light string passing over a massless and frictionless pulley (**Fig. E6.7**). Traveling at constant speed, the 20.0 N block moves 75.0 cm to the right and the 12.0 N block moves 72.0 cm downward. How much work is done (a) on the 12.0 N block by (i) gravity and (ii) the tension in the string? (b) How much work is done on the 20.0 N block by (i) gravity, (ii) the tension in the string, (iii) friction, and (iv) the normal force? (c) Find the total work done on each block.



**6.8** • A loaded shopping trolley is rolling across a parking lot in a strong wind. You apply a constant force  $\vec{F} = (30 \text{ N})\hat{i} - (37 \text{ N})\hat{j}$  to the trolley as it undergoes a displacement  $\vec{s} = (-8.6 \text{ m})\hat{i} - (3.8 \text{ m})\hat{j}$ . How much work does the force you apply do on the shopping trolley?

**6.9** • Your physics book is resting in front of you on a horizontal table in the campus library. You push the book over to your friend, who is seated at the other side of the table, 0.400 m north and 0.300 m east of you. If you push the book in a straight line to your friend, friction does  $-4.8 \text{ J}$  of work on the book. If instead you push the book 0.400 m due north and then 0.300 m due east, how much work is done by friction?

**6.10 ••** A 12.0 kg package in a mail-sorting room slides 2.00 m down a chute that is inclined at  $53.0^\circ$  below the horizontal. The coefficient of kinetic friction between the package and the chute's surface is 0.40. Calculate the work done on the package by (a) friction, (b) gravity, and (c) the normal force. (d) What is the net work done on the package?

**6.11 •** A force  $\vec{F}$  that is at an angle  $60^\circ$  above the horizontal is applied to a box that moves on a horizontal frictionless surface, and the force does work  $W$  as the box moves a distance  $d$ . (a) At what angle above the horizontal would the force have to be directed in order for twice the work to be done for the same displacement of the box? (b) If the angle is kept at  $60^\circ$  and the box is initially at rest, by what factor would  $F$  have to be increased to double the final speed of the box after moving distance  $d$ ?

**6.12 ••** A boxed 11.0-kg computer monitor is dragged by friction 5.50 m upward along a conveyor belt inclined at an angle of  $35.6^\circ$  above the horizontal. If the monitor's speed is a constant 3.00 cm/s, how much work is done on the monitor by (a) friction, (b) gravity, and (c) the normal force of the conveyor belt?

**6.13 ••** A large crate sits on the floor of a warehouse. Paul and Bob apply constant horizontal forces to the crate. The force applied by Paul has magnitude 48.0 N and direction  $61.0^\circ$  south of west. How much work does Paul's force do during a displacement of the crate that is 12.0 m in the direction  $22.0^\circ$  east of north?

**6.14 ••** You apply a constant force  $\vec{F} = (-68.0 \text{ N})\hat{i} + (36.0 \text{ N})\hat{j}$  to a 440-kg car as the car travels 48.0 m in a direction that is  $240.0^\circ$  counterclockwise from the  $+x$ -axis. How much work does the force you apply do on the car?

**6.15 ••** On a farm, you are pushing on a stubborn pig with a constant horizontal force with magnitude 30.0 N and direction  $37.0^\circ$  counterclockwise from the  $+x$ -axis. How much work does this force do during a displacement of the pig that is (a)  $\vec{s} = (5.00 \text{ m})\hat{i}$ ; (b)  $\vec{s} = -(6.00 \text{ m})\hat{j}$ ; (c)  $\vec{s} = -(2.00 \text{ m})\hat{i} + (4.00 \text{ m})\hat{j}$ ?

## Section 6.2 Kinetic Energy and the Work-Energy Theorem

**6.16 ••** A 1.50 kg book is sliding along a rough horizontal surface. At point A it is moving at 3.21 m/s, and at point B it has slowed to 1.25 m/s. (a) How much total work was done on the book between A and B? (b) If  $-0.750 \text{ J}$  of total work is done on the book from B to C, how fast is it moving at point C? (c) How fast would it be moving at C if  $+0.750 \text{ J}$  of total work was done on it from B to C?

**6.17 •• BIO Animal Energy.** Adult cheetahs, the fastest of the great cats, have a mass of about 70 kg and have been clocked to run at up to 32 m/s (around 115 km/h). (a) How many joules of kinetic energy does such a swift cheetah have? (b) By what factor would its kinetic energy change if its speed were doubled?

**6.18 ••** A baseball has a mass of 0.145 kg. (a) In batting practice a batter hits a ball that is sitting at rest on top of a post. The ball leaves the post with a horizontal speed of 30.0 m/s. How much work did the force applied by the bat do on the ball? (b) During a game the same batter swings at a ball thrown by the pitcher and hits it in such a way that the ball moves away from him horizontally. Just before the ball is hit it is traveling at a speed of 20.0 m/s, and just after it is hit it is traveling in the opposite direction at a speed of 30.0 m/s. What is the total work done on the baseball by the force exerted by the bat? (c) How do the results of parts (a) and (b) compare? Explain.

**6.19 • Chicxulub impact.** About 66 million years ago, an asteroid crashed into Earth near the present-day town of Chicxulub in Mexico (Yucatán Peninsula.) The impact produced a crater of about 180 km in diameter and its effects are believed to have caused a massive extinction of plant and animal groups, including dinosaurs. According to recent simulations (2019), the asteroid had a mass of about  $2.4 \times 10^{15} \text{ kg}$  and a velocity of about 20 km/s. (a) How much kinetic energy did this meteor deliver to the ground? (b) How does this energy compare to the energy released by a

1.0 megaton nuclear bomb? (A megaton bomb releases the same amount of energy as a million tonnes or  $10^9 \text{ kg}$  of TNT,  $4.184 \times 10^{15} \text{ J}$  of energy.)

**6.20 •** A 5.10-kg watermelon is dropped from rest from the roof of a 29.0-m-tall building and feels no appreciable air resistance. (a) Calculate the work done by gravity on the watermelon during its displacement from the roof to the ground. (b) Just before it strikes the ground, what is the watermelon's (i) kinetic energy and (ii) speed? (c) Which of the answers in parts (a) and (b) would be *different* if there were appreciable air resistance?

**6.21 • CP** You are pushing a large box across a frictionless floor by applying a constant horizontal force. If the box starts at rest, you have to do work  $W_1$  in order for the box to travel a distance  $d$  in time  $t$ . How much work would you have to do, in terms of  $W_1$ , to make the box go the same distance in half the time?

**6.22 ••** Use the work-energy theorem to solve each of these problems. You can use Newton's laws to check your answers. (a) A skier moving at 5.00 m/s encounters a long, rough horizontal patch of snow having a coefficient of kinetic friction of 0.220 with her skis. How far does she travel on this patch before stopping? (b) Suppose the rough patch in part (a) was only 2.90 m long. How fast would the skier be moving when she reached the end of the patch? (c) At the base of a frictionless icy hill that rises at  $25.0^\circ$  above the horizontal, a toboggan has a speed of 12.0 m/s toward the hill. How high vertically above the base will it go before stopping?

**6.23 ••** You are a member of an Alpine Rescue Team. You must project a box of supplies up an incline of constant slope angle  $\alpha$  so that it reaches a stranded skier who is a vertical distance  $h$  above the bottom of the incline. The incline is slippery, but there is some friction present, with kinetic friction coefficient  $\mu_k$ . Use the work-energy theorem to calculate the minimum speed you must give the box at the bottom of the incline so that it will reach the skier. Express your answer in terms of  $g$ ,  $h$ ,  $\mu_k$ , and  $\alpha$ .

**6.24 ••** You throw a 3.00 N rock vertically into the air from ground level. You observe that when it is 15.0 m above the ground, it is traveling at 25.0 m/s upward. Use the work-energy theorem to find (a) the rock's speed just as it left the ground and (b) its maximum height.

**6.25 •** A sled with mass 8.50 kg moves in a straight line on a frictionless, horizontal surface. At one point in its path, its speed is 4.20 m/s; after it has traveled 2.30 m beyond this point, its speed is 5.60 m/s. Use the work-energy theorem to find the force acting on the sled, assuming that this force is constant and that it acts in the direction of the sled's motion.

**6.26 ••** A football with mass 0.470 kg is initially moving with speed 2.10 m/s. A football player kicks the ball, exerting a constant force of magnitude 41.0 N in the same direction as the ball's motion. Over what distance must the player's foot be in contact with the ball to increase the ball's speed to 6.00 m/s?

**6.27 •** A 12-pack of Omni-Cola (mass 4.30 kg) is initially at rest on a horizontal floor. It is then pushed in a straight line for 1.20 m by a trained dog that exerts a horizontal force with magnitude 36.0 N. Use the work-energy theorem to find the final speed of the 12-pack if (a) there is no friction between the 12-pack and the floor, and (b) the coefficient of kinetic friction between the 12-pack and the floor is 0.30.

**6.28 ••** A block of ice with mass 2.00 kg slides 1.35 m down an inclined plane that slopes downward at an angle of  $36.9^\circ$  below the horizontal. If the block of ice starts from rest, what is its final speed? Ignore friction.

**6.29 •** Object A has 27 J of kinetic energy. Object B has one-quarter the mass of object A. (a) If object B also has 27 J of kinetic energy, is it moving faster or slower than object A? By what factor? (b) By what factor does the speed of each object change if total work  $-18 \text{ J}$  is done on each?

**6.30 ••** A 36.0 kg crate is initially moving with a velocity that has magnitude 3.73 m/s in a direction  $37.0^\circ$  west of north. How much work must be done on the crate to change its velocity to 5.40 m/s in a direction  $63.0^\circ$  south of east?

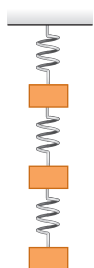
**6.31 • Stopping Distance.** A car is traveling on a level road with speed  $v_0$  at the instant when the brakes lock, so that the tires slide rather than roll. (a) Use the work–energy theorem to calculate the minimum stopping distance of the car in terms of  $v_0$ ,  $g$ , and the coefficient of kinetic friction  $\mu_k$  between the tires and the road. (b) By what factor would the minimum stopping distance change if (i) the coefficient of kinetic friction were doubled, or (ii) the initial speed were doubled, or (iii) both the coefficient of kinetic friction and the initial speed were doubled?

### Section 6.3 Work and Energy with Varying Forces

**6.32 ••** To stretch a spring 9.00 cm from its unstretched length, 19.0 J of work must be done. (a) What is the force constant of this spring? (b) What magnitude force is needed to stretch the spring 9.00 cm from its unstretched length? (c) How much work must be done to compress this spring 4.00 cm from its unstretched length, and what force is needed to compress it this distance?

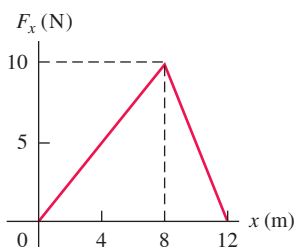
**6.33 •** Three identical 8.50 kg masses are hung by three identical springs (Fig. E6.33). Each spring has a force constant of 7.80 kN/m and was 12.0 cm long before any masses were attached to it. (a) Draw a free-body diagram of each mass. (b) How long is each spring when hanging as shown? (Hint: First isolate only the bottom mass. Then treat the bottom two masses as a system. Finally, treat all three masses as a system.)

Figure E6.33



**6.34 •** A child applies a force  $\vec{F}$  parallel to the  $x$ -axis to a 10.0 kg sled moving on the frozen surface of a small pond. As the child controls the speed of the sled, the  $x$ -component of the force she applies varies with the  $x$ -coordinate of the sled as shown in Fig. E6.34. Calculate the work done by  $\vec{F}$  when the sled moves (a) from  $x = 0$  to  $x = 8.0$  m; (b) from  $x = 8.0$  m to  $x = 12.0$  m; (c) from  $x = 0$  to  $x = 12.0$  m.

Figure E6.34



**6.35 ••** Suppose the sled in Exercise 6.34 is initially at rest at  $x = 0$ . Use the work–energy theorem to find the speed of the sled at (a)  $x = 8.0$  m and (b)  $x = 12.0$  m. Ignore friction between the sled and the surface of the pond.

**6.36 ••** A spring of force constant 300.0 N/m and unstretched length 0.240 m is stretched by two forces, pulling in opposite directions at opposite ends of the spring, that increase to 15.0 N. How long will the spring now be, and how much work was required to stretch it that distance?

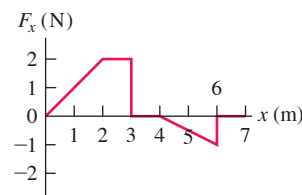
**6.37 ••** A 6.0 kg box moving at 3.0 m/s on a horizontal, frictionless surface runs into one end of a light horizontal spring of force constant 75 N/cm that is fixed at the other end. Use the work–energy theorem to find the maximum compression of the spring.

**6.38 •• Leg Presses.** As part of your daily workout, you lie on your back and push with your feet against a platform attached to two stiff springs arranged side by side so that they are parallel to each other. When you push the platform, you compress the springs. You do 77.0 J of work when you compress the springs 0.210 m from their uncompressed length. (a) What magnitude of force must you apply to hold the platform in this position? (b) How much *additional* work must you do to move the platform 0.210 m *further*; and what maximum force must you apply?

**6.39 ••** (a) In Example 6.7 (Section 6.3) it was calculated that with the air track turned off, the glider travels 8.6 cm before it stops instantaneously. How large would the coefficient of static friction  $\mu_s$  have to be to keep the glider from springing back to the left? (b) If the coefficient of static friction between the glider and the track is  $\mu_s = 0.60$ , what is the maximum initial speed  $v_1$  that the glider can be given and still remain at rest after it stops instantaneously? With the air track turned off, the coefficient of kinetic friction is  $\mu_k = 0.47$ .

**6.40 •** A 3.70-kg block of ice is placed against a horizontal spring that has force constant  $k = 250$  N/m and is compressed 0.021 m. The spring is released and accelerates the block along a horizontal surface. Ignore friction and the mass of the spring. (a) Calculate the work done on the block by the spring during the motion of the block from its initial position to where the spring has returned to its uncompressed length. (b) What is the speed of the block after it leaves the spring?

**6.41 •** A force  $\vec{F}$  is applied to a 2.0-kg, radio-controlled model car parallel to the  $x$ -axis as it moves along a straight track. The  $x$ -component of the force varies with the  $x$ -coordinate of the car (Fig. E6.41). Calculate the work done by the force  $\vec{F}$  when the car moves from



(a)  $x = 0$  to  $x = 3.0$  m; (b)  $x = 3.0$  m to  $x = 4.0$  m; (c)  $x = 4.0$  m to  $x = 7.0$  m; (d)  $x = 0$  to  $x = 7.0$  m; (e)  $x = 7.0$  m to  $x = 2.0$  m.

**6.42 •** Suppose the 2.0 kg model car in Exercise 6.41 is initially at rest at  $x = 0$  and  $\vec{F}$  is the net force acting on it. Use the work–energy theorem to find the speed of the car at (a)  $x = 3.0$  m; (b)  $x = 4.0$  m; (c)  $x = 7.0$  m.

**6.43 ••** At a waterpark, sleds with riders are sent along a slippery, horizontal surface by the release of a large compressed spring. The spring, with force constant  $k = 4100$  N/m and negligible mass, rests on the frictionless horizontal surface. One end is in contact with a stationary wall. A sled and rider with total mass 74.0 kg are pushed against the other end, compressing the spring 0.395 m. The sled is then released with zero initial velocity. What is the sled's speed when the spring (a) returns to its uncompressed length and (b) is still compressed 0.220 m?

**6.44 ••** A small glider is placed against a compressed spring at the bottom of an air track that slopes upward at an angle of  $40.0^\circ$  above the horizontal. The glider has mass 0.0900 kg. The spring has  $k = 640$  N/m and negligible mass. When the spring is released, the glider travels a maximum distance of 1.80 m along the air track before sliding back down. Before reaching this maximum distance, the glider loses contact with the spring. (a) What distance was the spring originally compressed? (b) When the glider has traveled along the air track 0.80 m from its initial position against the compressed spring, is it still in contact with the spring? What is the kinetic energy of the glider at this point?

**6.45 •• CALC** A force in the  $+x$ -direction with magnitude  $F(x) = 18.0 \text{ N} - (0.530 \text{ N/m})x$  is applied to a 5.00 kg box that is sitting on the horizontal, frictionless surface of a frozen lake.  $F(x)$  is the only horizontal force on the box. If the box is initially at rest at  $x = 0$ , what is its speed after it has traveled 11.0 m?

### Section 6.4 Power

**6.46 ••** A crate on a motorized cart starts from rest and moves with a constant eastward acceleration of  $a = 2.60 \text{ m/s}^2$ . A worker assists the cart by pushing on the crate with a force that is eastward and has magnitude that depends on time according to  $F(t) = (5.40 \text{ N/s})t$ . What is the instantaneous power supplied by this force at  $t = 4.70$  s?

**6.47 •** How many joules of energy does a 100 watt light bulb use per hour? How fast would a 75 kg person have to run to have that amount of kinetic energy?

**6.48 •• BIO Should You Walk or Run?** It is 5.0 km from your home to the physics lab. As part of your physical fitness program, you could run that distance at 10 km/h (which uses up energy at the rate of 700 W), or you could walk it leisurely at 3.0 km/h (which uses energy at 290 W). Which choice would burn up more energy, and how much energy (in joules) would it burn? Why does the more intense exercise burn up less energy than the less intense exercise?

**6.49 •** Estimate how many 12.7 kg boxes of copy paper an average student in your physics class can load into a van in 5.0 min. The van has a loading height of 0.7 m. If you assume that the magnitude of the work done on each box by the student equals the magnitude of the work done on the box by gravity when the box is lifted into the van, what is the average power output of the student?

**6.50 ••** A 20.0 kg rock is sliding on a rough, horizontal surface at 8.00 m/s and eventually stops due to friction. The coefficient of kinetic friction between the rock and the surface is 0.200. What average power is produced by friction as the rock stops?

**6.51 •** A student walks up three flights of stairs, a vertical height of about 10 m. Estimate the student's weight to be the average for students in your physics class. If the magnitude of the average rate at which the gravity force does work on the student equals 500 W, how long would it take the student to travel up the three flights of stairs?

**6.52 ••** When its 75 kW engine is generating full power, a small single-engine airplane with mass 700 kg gains altitude at a rate of 2.5 m/s (150 m/min). What fraction of the engine power is being used to make the airplane climb? (The remainder is used to overcome the effects of air resistance and of inefficiencies in the propeller and engine.)

**6.53 ••** Your job is to lift 30 kg crates a vertical distance of 0.90 m from the ground onto the bed of a truck. (a) If on average you can load 3 crates a minute onto the truck, what is your average power output? (b) How many crates would you have to load onto the truck in 1 minute for an average power output of 100 W?

**6.54 ••** A lift has mass 600 kg, not including passengers. The lift is designed to ascend, at constant speed, a vertical distance of 20.0 m (five floors) in 16.0 s, and it is driven by a motor that can provide up to 30 kW to the lift. What is the maximum number of passengers that can ride in the lift? Assume that an average passenger has mass 65.0 kg.

**6.55 ••** A ski tow operates on a 14.0° slope of length 340 m. The rope moves at 11.5 km/h and provides power for 55 riders at one time, with an average mass per rider of 70.0 kg. Estimate the power required to operate the tow.

**6.56 •** You are applying a constant horizontal force  $\vec{F} = (-8.00 \text{ N})\hat{i} + (3.00 \text{ N})\hat{j}$  to a crate that is sliding on a factory floor. At the instant that the velocity of the crate is  $\vec{v} = (3.20 \text{ m/s})\hat{i} + (2.20 \text{ m/s})\hat{j}$ , what is the instantaneous power supplied by this force?

**6.57 • BIO** While hovering, a typical flying insect applies an average force equal to twice its weight during each downward stroke. Take the mass of the insect to be 10 g, and assume the wings move an average downward distance of 1.0 cm during each stroke. Assuming 100 downward strokes per second, estimate the average power output of the insect.

## PROBLEMS

**6.58 ••• CALC** An uncooperative cow is leaving the barn as you try harder and harder to push her back in. In coordinates with the origin at the barn door, the cow walks from  $x = 0$  to  $x = 6.9 \text{ m}$  as you apply a force with  $x$ -component  $F_x = -[20.0 \text{ N} + (3.0 \text{ N/m})x]$ . How much work does the force you apply do on the cow during this displacement?

**6.59 •** A luggage handler pulls a 20.0 kg suitcase up a ramp inclined at 32.0° above the horizontal by a force  $\vec{F}$  of magnitude 160 N that acts parallel to the ramp. The coefficient of kinetic friction between the ramp and the incline is  $\mu_k = 0.300$ . If the suitcase travels 3.80 m along the ramp, calculate (a) the work done on the suitcase by  $\vec{F}$ ; (b) the work done on the suitcase by the gravitational force; (c) the work done on the suitcase by the normal force; (d) the work done on the suitcase by the friction force; (e) the total work done on the suitcase. (f) If the speed of the suitcase is zero at the bottom of the ramp, what is its speed after it has traveled 3.80 m along the ramp?

**6.60 •• CP** A can of beans that has mass  $M$  is launched by a spring-powered device from level ground. The can is launched at an angle of  $\alpha_0$  above the horizontal and is in the air for time  $T$  before it returns to the ground. Air resistance can be neglected. (a) How much work was done on the can by the launching device? (b) How much work is done on the can if it is launched at the same angle  $\alpha_0$  but stays in the air twice as long? How does your result compare to the answer to part (a)?

**6.61 ••** A 5.00 kg block is released from rest on a ramp that is inclined at an angle of 60.0° below the horizontal. The initial position of the block is a vertical distance of 2.00 m above the bottom of the ramp. (a) If the speed of the block is 5.00 m/s when it reaches the bottom of the ramp, what was the work done on it by the friction force? (b) If the angle of the ramp is changed but the block is released from a point that is still 2.00 m above the base of the ramp, both the magnitude of the friction force and the distance along the ramp that the block travels change. If the angle of the incline is changed to 50.0°, does the magnitude of the work done by the friction force increase or decrease compared to the value calculated in part (a)? (c) How much work is done by friction when the ramp angle is 50.0°?

**6.62 ••** A block of mass  $m$  is released from rest at the top of an incline that makes an angle  $\alpha$  with the horizontal. The coefficient of kinetic friction between the block and incline is  $\mu_k$ . The top of the incline is a vertical distance  $h$  above the bottom of the incline. Derive an expression for the work  $W_f$  done on the block by friction as it travels from the top of the incline to the bottom. When  $\alpha$  is decreased, does the magnitude of  $W_f$  increase or decrease?

**6.63 •••** Consider the blocks in Exercise 6.7 as they move 75.0 cm. Find the total work done on each one (a) if there is no friction between the table and the 20.0 N block, and (b) if  $\mu_s = 0.500$  and  $\mu_k = 0.325$  between the table and the 20.0 N block.

**6.64 ••** A 5.20 kg package slides 1.41 m down a long ramp that is inclined at 13.0° below the horizontal. The coefficient of kinetic friction between the package and the ramp is  $\mu_k = 0.313$ . Calculate (a) the work done on the package by friction; (b) the work done on the package by gravity; (c) the work done on the package by the normal force; (d) the total work done on the package. (e) If the package has a speed of 2.22 m/s at the top of the ramp, what is its speed after it has slid 1.41 m down the ramp?

**6.65 •• CP BIO Whiplash Injuries.** When a car is hit from behind, its passengers undergo sudden forward acceleration, which can cause a severe neck injury known as *whiplash*. During normal acceleration, the neck muscles play a large role in accelerating the head so that the bones are not injured. But during a very sudden acceleration, the muscles do not react immediately because they are flexible; most of the accelerating force is provided by the neck bones. Experiments have shown that these bones will fracture if they absorb more than 8.0 J of energy. (a) If a car waiting at a stoplight is rear-ended in a collision that lasts for 10.0 ms, what is the greatest speed this car and its driver can reach without breaking neck bones if the driver's head has a mass of 5.0 kg (which is about right for a 70 kg person)? Express your answer in m/s and in km/h. (b) What is the acceleration of the passengers during the collision in part

(a), and how large a force is acting to accelerate their heads? Express the acceleration in  $\text{m/s}^2$  and in  $g$ 's.

**6.66 • CALC** A net force along the  $x$ -axis that has  $x$ -component  $F_x = -12.0 \text{ N} + (0.300 \text{ N/m}^2)x^2$  is applied to a  $5.00 \text{ kg}$  object that is initially at the origin and moving in the  $-x$ -direction with a speed of  $6.00 \text{ m/s}$ . What is the speed of the object when it reaches the point  $x = 5.00 \text{ m}$ ?

**6.67 • CALC Varying Coefficient of Friction.** A box is sliding with a speed of  $4.50 \text{ m/s}$  on a horizontal surface when, at point  $P$ , it encounters a rough section. The coefficient of friction there is not constant; it starts at  $0.100$  at  $P$  and increases linearly with distance past  $P$ , reaching a value of  $0.600$  at  $12.5 \text{ m}$  past point  $P$ . (a) Use the work–energy theorem to find how far this box slides before stopping. (b) What is the coefficient of friction at the stopping point? (c) How far would the box have slid if the friction coefficient didn't increase but instead had the constant value of  $0.100$ ?

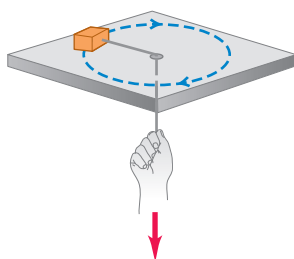
**6.68 • CALC** Consider a spring that does not obey Hooke's law very faithfully. One end of the spring is fixed. To keep the spring stretched or compressed an amount  $x$ , a force along the  $x$ -axis with  $x$ -component  $F_x = kx - bx^2 + cx^3$  must be applied to the free end. Here  $k = 100 \text{ N/m}$ ,  $b = 700 \text{ N/m}^2$ , and  $c = 12,000 \text{ N/m}^3$ . Note that  $x > 0$  when the spring is stretched and  $x < 0$  when it is compressed. How much work must be done (a) to stretch this spring by  $0.050 \text{ m}$  from its unstretched length? (b) To compress this spring by  $0.050 \text{ m}$  from its unstretched length? (c) Is it easier to stretch or compress this spring? Explain why in terms of the dependence of  $F_x$  on  $x$ . (Many real springs behave qualitatively in the same way.)

**6.69 ••** A net horizontal force  $\vec{F}$  is applied to a box with mass  $M$  that is on a horizontal, frictionless surface. The box is initially at rest and then moves in the direction of the force. After the box has moved a distance  $D$ , the work that the constant force has done on it is  $W_D$  and the speed of the box is  $V$ . The equation  $P = Fv$  tells us that the instantaneous rate at which  $\vec{F}$  is doing work on the box depends on the speed of the box. (a) At the point in the motion of the box where the force has done half the total work, and so has done work  $W_D/2$  on the box that started from rest, in terms of  $V$  what is the speed of the box? Is the speed at this point less than, equal to, or greater than half the final speed? (b) When the box has reached half its final speed, so its speed is  $V/2$ , how much work has been done on the box? Express your answer in terms of  $W_D$ . Is the amount of work done to produce this speed less than, equal to, or greater than half the work  $W_D$  done for the full displacement  $D$ ?

**6.70 ••** You weigh  $530 \text{ N}$ . Your bathroom scale contains a light but very stiff ideal spring. When you stand at rest on the scale, the spring is compressed  $1.80 \text{ cm}$ . Your  $180 \text{ N}$  dog then gently jumps into your arms. How much work is done by the spring as the two of you are brought to rest by friction?

**6.71 •• CP** A small block with a mass of  $0.0600 \text{ kg}$  is attached to a cord passing through a hole in a frictionless, horizontal surface (Fig. P6.71). The block is originally revolving at a distance of  $0.40 \text{ m}$  from the hole with a speed of  $0.70 \text{ m/s}$ . The cord is then pulled from below, shortening the radius of the circle in which the block revolves to  $0.10 \text{ m}$ . At this new distance, the speed of the block is  $2.80 \text{ m/s}$ . (a) What is the tension in the cord in the original situation, when the block has speed  $v = 0.70 \text{ m/s}$ ? (b) What is the tension in the cord in the final situation, when the block has speed  $v = 2.80 \text{ m/s}$ ? (c) How much work was done by the person who pulled on the cord?

Figure P6.71



**6.72 •• CALC Proton Bombardment.** A proton with mass  $1.67 \times 10^{-27} \text{ kg}$  is propelled at an initial speed of  $3.00 \times 10^5 \text{ m/s}$  directly toward a uranium nucleus  $5.00 \text{ m}$  away. The proton is repelled by the uranium nucleus with a force of magnitude  $F = \alpha/x^2$ , where  $x$  is the separation between the two objects and  $\alpha = 2.12 \times 10^{-26} \text{ N} \cdot \text{m}^2$ . Assume that the uranium nucleus remains at rest. (a) What is the speed of the proton when it is  $8.00 \times 10^{-10} \text{ m}$  from the uranium nucleus? (b) As the proton approaches the uranium nucleus, the repulsive force slows down the proton until it comes momentarily to rest, after which the proton moves away from the uranium nucleus. How close to the uranium nucleus does the proton get? (c) What is the speed of the proton when it is again  $5.00 \text{ m}$  away from the uranium nucleus?

**6.73 ••** You are asked to design spring bumpers for the walls of a parking garage. A freely rolling  $1200 \text{ kg}$  car moving at  $0.65 \text{ m/s}$  is to compress the spring no more than  $0.090 \text{ m}$  before stopping. What should be the force constant of the spring? Assume that the spring has negligible mass.

**6.74 ••** You and your bicycle have combined mass  $80.0 \text{ kg}$ . When you reach the base of a bridge, you are traveling along the road at  $7.50 \text{ m/s}$  (Fig. P6.74). At the top of the bridge, you have climbed a vertical distance of  $5.20 \text{ m}$  and slowed to  $2.50 \text{ m/s}$ . Ignore work done by friction and any inefficiency in the bike or your legs. (a) What is the total work done on you and your bicycle when you go from the base to the top of the bridge? (b) How much work have you done with the force you apply to the pedals?

Figure P6.74



**6.75 •••** A  $2.90 \text{ kg}$  textbook is forced against a horizontal spring of negligible mass and force constant  $290 \text{ N/m}$ , compressing the spring a distance of  $0.300 \text{ m}$ . When released, the textbook slides on a horizontal tabletop with coefficient of kinetic friction  $\mu_k = 0.30$ . Use the work–energy theorem to find how far the textbook moves from its initial position before it comes to rest.

**6.76 ••** The spring of a spring gun has force constant  $k = 400 \text{ N/m}$  and negligible mass. The spring is compressed  $6.00 \text{ cm}$ , and a ball with mass  $0.0300 \text{ kg}$  is placed in the horizontal barrel against the compressed spring. The spring is then released, and the ball is propelled out the barrel of the gun. The barrel is  $6.00 \text{ cm}$  long, so the ball leaves the barrel at the same point that it loses contact with the spring. The gun is held so that the barrel is horizontal. (a) Calculate the speed with which the ball leaves the barrel if you can ignore friction. (b) Calculate the speed of the ball as it leaves the barrel if a constant resisting force of  $6.00 \text{ N}$  acts on the ball as it moves along the barrel. (c) For the situation in part (b), at what position along the barrel does the ball have the greatest speed, and what is that speed? (In this case, the maximum speed does not occur at the end of the barrel.)