Work, Energy, and Power Worksheet

24 problems + 3 challenge
Answer key at the back

Name _____ Date _____ Period _____

Directions. Use g = 9.8 m/s², neglect air resistance unless a problem gives it, and treat surfaces as frictionless unless a friction coefficient or force is given. Name the system before you write an energy equation. Keep unrounded values between steps and round final answers to three significant figures.

Part A: work. Part B: the work-energy theorem. Part C: conservation of energy. Part D: power. Problems 25 to 27 are a challenge set.

$W = F_{\parallel} d = Fd\cos\theta$	$W_{net} = \Delta K$	$\Delta K + \Delta U + \Delta E_{th} = W_{ext}$	$P = W / \Delta t = F_{\parallel} v$

Part A: Work

$W = F_{\parallel} d = Fd\cos\theta$ for a constant force, and the area under a force graph for a changing one.

1 A student pushes a 15.0 kg box 4.00 m across a level floor with a horizontal force of 60.0 N. The friction force on the box is 40.0 N. Find the work done on the box by (a) the push, (b) friction, (c) gravity, and (d) the normal force. (e) Find the net work.

Answer: _____

2 A rope pulls a cart 20.0 m along level ground. The tension is 50.0 N and the rope makes an angle of 35.0° with the ground. (a) How much work does the tension do? (b) How much work would the same tension do if the rope were horizontal?

Answer: _____

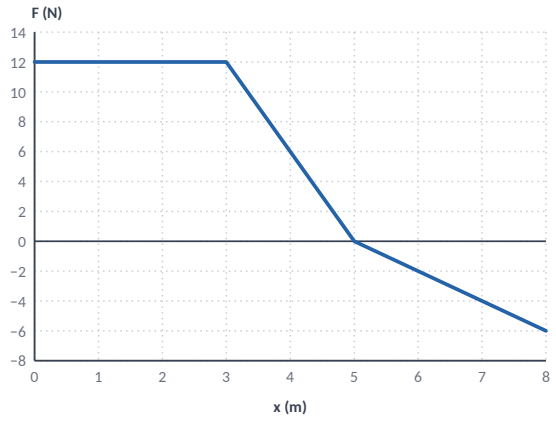
3 A person lifts a 2.00 kg book at constant velocity from the floor to a shelf 1.80 m high, then carries it 3.00 m horizontally at constant velocity and constant height. Find the work done on the book by the person (a) during the lift and (b) during the walk. (c) Find the work done by gravity over the whole trip.

Answer: _____

4 A 60.0 kg skier slides 120 m down a straight slope inclined at 25.0° below the horizontal. (a) How far does the skier drop vertically? (b) How much work does gravity do on the skier?

Answer: _____

5 The graph shows the horizontal force on a 4.00 kg crate on a level, frictionless floor as it moves from x = 0 to x = 8.00 m. The force is 12.0 N from 0 to 3.00 m, then decreases steadily to 0 at 5.00 m and to −6.00 N at 8.00 m. Find the work done by the force (a) from 0 to 5.00 m, (b) from 5.00 m to 8.00 m, and (c) from 0 to 8.00 m. (d) If the crate starts from rest at x = 0, at what position is its speed greatest?



KEY

———	Force on the crate, F
———	F = 0

Answer: _____

6 A 0.250 kg puck on a frictionless, level table is tied to a peg by a string and moves in a circle of radius 0.800 m at constant speed. The tension in the string is 5.00 N. How much work does the tension do on the puck during (a) a quarter of a revolution and (b) one full revolution? Explain.

Answer: _____

Part B: The work-energy theorem

$W_{net} = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$.

7 A pitcher throws a 0.145 kg baseball. The ball starts from rest and leaves the hand at 40.0 m/s after the hand pushes it along a 1.80 m path. Ignoring other forces, find (a) the work done on the ball by the pitcher and (b) the average force the hand exerts along the path.

Answer: _____

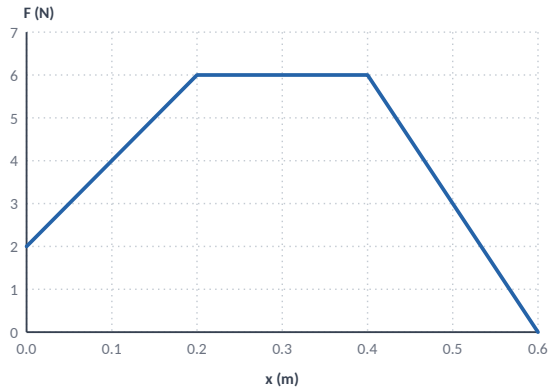
8 A 1,200 kg car traveling at 25.0 m/s brakes to a stop in 50.0 m on a level road. Find (a) the work done on the car by the braking force and (b) the size of the average braking force.

Answer: _____

9 A cyclist skids to a stop from 6.00 m/s in 4.50 m. On the same road, with the same friction, how far would she skid from 9.00 m/s?

Answer: _____

10 The graph shows the net horizontal force on a 0.500 kg cart that starts from rest at x = 0. The force is 2.00 N at x = 0, rises steadily to 6.00 N at x = 0.200 m, stays at 6.00 N until x = 0.400 m, then decreases steadily to 0 at x = 0.600 m. Find the cart's speed at (a) x = 0.400 m and (b) x = 0.600 m.



Answer: _____

11 A 3.00 kg block is pushed so that it starts sliding up a 20.0° incline at 6.00 m/s. The coefficient of kinetic friction is 0.250. How far up the incline does the block slide before it stops?

Answer: _____

12 Carts P and Q start from rest on a level, frictionless track. Q has twice the mass of P. The same constant force F pushes each cart through the same distance d. Compare (a) their final kinetic energies and (b) their final speeds.

Answer: _____

Part C: Conservation of energy

Name the system first. Include thermal energy, ΔE_{th}, when friction or air resistance acts.

13 A 450 kg roller coaster car passes over the top of a 40.0 m hill at 4.00 m/s. Ignoring friction, find its speed (a) at ground level and (b) at the top of the next hill, which is 25.0 m high.

Answer: _____

14 A 25.0 kg child slides from rest down a playground slide whose top is 2.50 m above its bottom. Her speed at the bottom is 4.20 m/s. (a) How much mechanical energy became thermal energy? (b) What fraction of the starting gravitational potential energy is that?

Answer: _____

15 A 0.800 kg block is pushed against a horizontal spring (k = 500 N/m), compressing it 0.200 m, and released from rest. The block is not attached to the spring, and μ_k = 0.300 between the block and the floor. Find (a) the block's speed when it leaves the spring at the spring's relaxed length and (b) the total distance it slides from the release point before stopping.

Answer: _____

16 A 0.600 kg ball is thrown straight up at 15.0 m/s and reaches a maximum height of 10.5 m above the release point. (a) How much mechanical energy did air resistance remove on the way up? (b) What was the average force of air resistance? (c) Will the ball return to the release point faster or slower than 15.0 m/s? Explain.

Answer: _____

17 A 2.00 kg ball falls 5.00 m from rest. Student 1 writes that gravity does +98.0 J of work on the ball. Student 2 writes that the gravitational potential energy decreases by 98.0 J. (a) Who is right? (b) What goes wrong if one energy equation includes both terms? (c) Find the ball's speed after it has fallen 5.00 m.

Answer: _____

18 A 4.00 kg block slides from rest down a frictionless curved ramp from a height of 1.20 m, then moves onto a level floor where $\mu_k = 0.400$. Find (a) its speed at the bottom of the ramp and (b) how far it slides on the floor before stopping.

Answer: _____

Part D: Power

$P_{avg} = W / \Delta t = \Delta E / \Delta t$, and $P = F_{\parallel} v$ for a constant force on an object moving at speed v.

19 A 55.0 kg student climbs a flight of stairs 4.20 m high in 6.00 s. What is her average power output against gravity?

Answer: _____

20 A motor lifts a 300 kg freight elevator at a constant 1.50 m/s. Ignoring friction, what power does the motor deliver?

Answer: _____

21 A car's engine delivers 30.0 kW to the wheels while the car moves at a constant 25.0 m/s on a level road. What is the total force of air resistance and rolling friction on the car?

Answer: _____

22 A 1,500 W hair dryer runs for 12.0 minutes. Find the energy it uses (a) in joules and (b) in kilowatt-hours.

Answer: _____

23 A winch pulls a 90.0 kg crate up a 15.0° ramp at a constant 0.800 m/s. The coefficient of kinetic friction between the crate and the ramp is 0.200. What power does the winch deliver?

Answer: _____

24 A 1,000 kg car speeds up from rest to 20.0 m/s in 8.00 s on a level road. Ignore friction and assume the net force is constant. Find (a) the average power delivered to the car and (b) the instantaneous power at t = 8.00 s.

Answer: _____

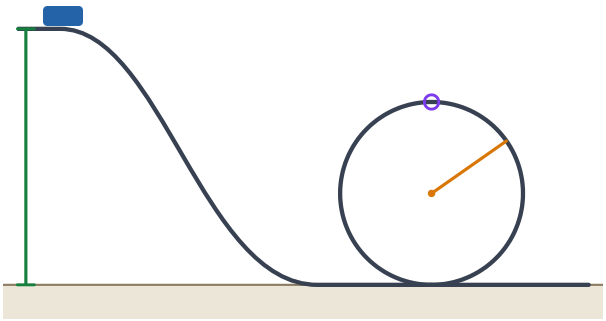
Challenge problems

Each one combines two ideas from this page.

25 A 2.00 kg block is dropped from rest 0.500 m above the top of a vertical spring with k = 800 N/m. Find the maximum compression of the spring.

Answer: _____

26 A 200 kg roller coaster car starts from rest and goes around a vertical loop of radius 8.00 m, as in the figure. (a) Without friction, what is the smallest starting height above the bottom of the loop that keeps the car on the track at the top of the loop? (b) If friction converts 4,900 J to thermal energy between the start and the top of the loop, what starting height is needed?



KEY

▬	Car at the start, at rest
I	Starting height h above the bottom of the loop
—	Loop radius R = 8.00 m
○	Top of the loop

Answer: _____

27 An 800 kg elevator car is connected by a cable over a pulley to a 650 kg counterweight. The car rises at a constant 2.00 m/s. Ignoring friction and the mass of the cable, what power must the motor supply? What power would it need without the counterweight?

Answer: _____

Answer key

$g = 9.8\ m/s^2$. Final answers are rounded to three significant figures, with unrounded values carried between steps. Guide, animations, and worked examples: burketutoringinfremont.com/ap-physics-1-work-energy-and-power-problems/

Part A: Work

1. (a) 60.0(4.00) = **240 J**. (b) −40.0(4.00) = **−160 J**. (c) **0**, because gravity is perpendicular to the displacement. (d) **0**, for the same reason. (e) 240 − 160 = **80.0 J**.

2. (a) $W = 50.0(20.0)\cos 35.0° =$ **819 J**. (b) $W = 50.0(20.0) =$ **1.00×10^3 J**. Only the component along the ground does work, so the angled rope does less.

3. (a) At constant velocity the hand pushes up with mg = 19.6 N through 1.80 m: W = 19.6(1.80) = **35.3 J**. (b) **0**. The hand's force is vertical and the displacement is horizontal. (c) $W_g = -mg\Delta y =$ **−35.3 J**. The walk adds nothing because the height does not change.

4. (a) Drop = 120 sin 25.0° = **50.7 m**. (b) W_g = mg × drop = 60.0(9.8)(50.71) = **2.98×10^4 J**. The angle between gravity and the motion is 65.0°, and mg(120) cos 65.0° gives the same result.

5. (a) Rectangle 12.0(3.00) = 36.0 J plus triangle ½(2.00)(12.0) = 12.0 J, total **48.0 J**. (b) Triangle below the axis: ½(3.00)(−6.00) = **−9.00 J**. (c) 48.0 − 9.00 = **39.0 J**. (d) At **x = 5.00 m**. The force points forward up to that position and backward after it, so the crate speeds up until 5.00 m and then slows down.

6. (a) **0** and (b) **0**. The tension points toward the peg, perpendicular to the puck's velocity at every point of the circle, so no part of the path has a displacement component along the force. The speed stays constant, which agrees with zero net work.

Part B: The work-energy theorem

7. (a) $W = \Delta K = \frac{1}{2}(0.145)(40.0)^2 =$ **116 J**. (b) F = W / d = 116 / 1.80 = **64.4 N**.

8. (a) $W = \Delta K = 0 - \frac{1}{2}(1{,}200)(25.0)^2 =$ **-3.75×10^5 J**. (b) F = 375,000 / 50.0 = **7.50×10^3 N**.

9. Friction removes all the kinetic energy, so $\mu_k mg \cdot d = \frac{1}{2}mv^2$ and d is proportional to v^2. $(9.00 / 6.00)^2 = 2.25$, so d = 2.25(4.50) = **10.1 m**.

10. Areas: trapezoid ½(2.00 + 6.00)(0.200) = 0.800 J, rectangle 6.00(0.200) = 1.20 J, triangle ½(0.200)(6.00) = 0.600 J. (a) W = 0.800 + 1.20 = 2.00 J = ½(0.500)v^2, so v = **2.83 m/s**. (b) W = 2.00 + 0.600 = 2.60 J, so v = **3.22 m/s**.

11. Both forces along the incline oppose the motion: the component of gravity, mg sin 20.0° = 10.1 N, and friction, $\mu_k$mg cos 20.0° = 6.91 N. Work-energy theorem: −(10.06 + 6.907)d = 0 − ½(3.00)(6.00)², so 16.96d = 54.0 and d = **3.18 m**.

12. (a) **Equal.** Each cart receives work Fd, so each ends with K = Fd. (b) $\frac{1}{2}mv_P^2 = \frac{1}{2}(2m)v_Q^2$, so $v_P = \sqrt{2}\, v_Q$, about **1.41 times** as fast. The lighter cart is faster.

Part C: Conservation of energy

13. With no friction, $\frac{1}{2}v^2 = \frac{1}{2}v_0^2 + g \times$ (height dropped), and the mass cancels. (a) $v = \sqrt{(4.00^2 + 2(9.8)(40.0))} = \sqrt{800} =$ **28.3 m/s**. (b) The car is 15.0 m below its starting height: $v = \sqrt{(4.00^2 + 2(9.8)(15.0))} = \sqrt{310} =$ **17.6 m/s**.

14. $U_g = 25.0(9.8)(2.50) = 612.5$ J and $K = \frac{1}{2}(25.0)(4.20)^2 = 220.5$ J. (a) $\Delta E_{th} = 612.5 - 220.5 =$ **392 J**. (b) 392 / 612.5 = 0.640, or **64.0%**.

15. $U_s = \frac{1}{2}(500)(0.200)^2 = 10.0$ J, and the friction force is $\mu_k mg = 0.300(0.800)(9.8) = 2.352$ N. (a) While the spring pushes, friction converts 2.352(0.200) = 0.470 J: ½(0.800)v^2 = 10.0 − 0.470, so v = **4.88 m/s**. (b) All 10.0 J ends up as thermal energy: 2.352d = 10.0, so d = **4.25 m**.

16. $K_0 = \frac{1}{2}(0.600)(15.0)^2 = 67.5$ J, and at the top $U_g = 0.600(9.8)(10.5) = 61.7$ J. (a) 67.5 − 61.74 = **5.76 J**. (b) F = 5.76 / 10.5 = **0.549 N**. (c) **Slower.** Air resistance removes more energy on the way down, so the ball returns with less than 67.5 J of kinetic energy. Without air resistance it would rise $v_0^2/2g = 11.5$ m, as in the thrown-up case of the free fall guide.

17. (a) **Both.** Student 1 chose the ball alone as the system, so gravity is an outside force that does work on it. Student 2 chose the ball and Earth, so the same transfer appears as a change in U_g. (b) The equation counts the transfer twice and gives K = **196 J**, twice the correct value. (c) $\frac{1}{2}(2.00)v^2 = 98.0$, so v = **9.90 m/s**.

18. (a) $v = \sqrt{2(9.8)(1.20)}$ = **4.85 m/s**. (b) Friction on the floor turns all of mgh into thermal energy: $mgh = \mu_k mg \cdot d$, so $d = h / \mu_k$ = 1.20 / 0.400 = **3.00 m**. The mass cancels.

Part D: Power

19. $W = mgh = 55.0(9.8)(4.20) = 2{,}264$ J. P = 2,264 / 6.00 = **377 W**.

20. At constant speed the motor's force equals mg, so P = mgv = 300(9.8)(1.50) = 4,410 W = **4.41 kW**.

21. At constant speed the driving force equals the resistive force. F = P / v = 30,000 / 25.0 = **1.20×10^3 N**.

22. (a) E = Pt = 1,500(720) = **1.08×10^6 J**. (b) E = 1.50 kW × 0.200 h = **0.300 kWh**.

23. At constant speed the pull is $mg(\sin 15.0° + \mu_k \cos 15.0°) = 882(0.2588 + 0.1932) = 399$ N. P = Fv = 398.7(0.800) = **319 W**.

24. (a) $\Delta K = \frac{1}{2}(1{,}000)(20.0)^2 = 2.00 \times 10^5$ J, so P_{avg} = 200,000 / 8.00 = **25.0 kW**. (b) a = 20.0 / 8.00 = 2.50 m/s², so F = ma = 2.50 × 10^3 N and P = Fv = 2,500(20.0) = **50.0 kW**. The speed grows steadily from 0 to 20.0 m/s, so the average power is half the final power.

Challenge problems

25. At maximum compression x the block is momentarily at rest, and it has fallen 0.500 + x. Energy: $mg(0.500 + x) = \frac{1}{2}kx^2$, so $400x^2 - 19.6x - 9.8 = 0$. The quadratic formula gives $x = [19.6 + \sqrt{(19.6^2 + 4(400)(9.8))}] / 800$ = **0.183 m**. The other root is negative.

26. At the smallest possible speed at the top, the normal force is zero and gravity alone provides the centripetal force: $mg = mv^2/R$, so $v^2 = gR = 78.4$ m²/s². (a) $mgh = mg(2R) + \frac{1}{2}m(gR)$, so $h = 2.5R$ = **20.0 m**. (b) $200(9.8)h = 200(9.8)(16.0) + \frac{1}{2}(200)(78.4) + 4{,}900 = 44{,}100$, so h = **22.5 m**.

27. Take the car, the counterweight, and Earth as the system. Each second the car gains 800(9.8)(2.00) = 15,680 J of U_g and the counterweight loses 650(9.8)(2.00) = 12,740 J. The kinetic energy stays constant, so the motor supplies the difference: 2,940 J/s = **2.94 kW**. Without the counterweight it would supply **15.7 kW**.