# 8

# Conservation of Energy

## CHAPTER OUTLINE



* An asterisk indicates a question or problem new to this edition.

## ANSWERS TO OBJECTIVE QUESTIONS

**OQ8.1** Answer (a). We assume the light band of the slingshot puts equal amounts of kinetic energy into the missiles. With three times more speed, the bean has nine times more squared speed, so it must have one-ninth the mass.

**OQ8.2** (i) Answer (b). Kinetic energy is proportional to mass.

(ii) Answer (c). The slide is frictionless, so $v = (2gh)^{1/2}$ in both cases.

(iii) Answer (a). $g$ for the smaller child and $g\sin\theta$ for the larger.

**OQ8.3** Answer (d). The static friction force that each glider exerts on the other acts over no distance relative to the surface of the other glider. The air track isolates the gliders from outside forces doing work. The gliders-Earth system keeps constant mechanical energy.

**OQ8.4** Answer (c). Once the athlete leaves the surface of the trampoline, only a conservative force (her weight) acts on her. Therefore, the total mechanical energy of the athlete-Earth system is constant during her flight: $K_f + U_f = K_i + U_i$. Taking the $y = 0$ at the surface of the trampoline, $U_i = mgy_i = 0$. Also, her speed when she reaches maximum height is zero, or $K_f = 0$. This leaves us with $U_f = K_i$, or $mgy_{\max} = \frac{1}{2}mv_i^2$, which gives the maximum height as

$$y_{\max} = \frac{v_i^2}{2g} = \frac{(8.5 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)} = 3.7 \text{ m}$$

**OQ8.5** (a) Yes: a block slides on the floor where we choose $y = 0$.

(b) Yes: a picture on the classroom wall high above the floor.

(c) Yes: an eraser hurtling across the room.

(d) Yes: the block stationary on the floor.

**OQ8.6** In order the ranking: c > a = d > b. We have $\frac{1}{2}mv^2 = \mu_k mgd$ so $d = v^2/2\mu_k g$. The quantity $v^2/\mu_k$ controls the skidding distance. In the cases quoted respectively, this quantity has the numerical values: (a) 5 (b) 1.25 (c) 20 (d) 5.

**OQ8.7** Answer (a). We assume the climber has negligible speed at both the beginning and the end of the climb. Then $K_f = K_i$, and the work done by the muscles is

$$\begin{aligned} W_{nc} &= 0 + (U_f - U_i) = mg(y_f - y_i) \\ &= (70.0 \text{ kg})(9.80 \text{ m/s}^2)(325 \text{ m}) \\ &= 2.23 \times 10^5 \text{ J} \end{aligned}$$

The average power delivered is

$$P = \frac{W_{nc}}{\Delta t} = \frac{2.23 \times 10^5 \text{J}}{(95.0 \text{ min})(60 \text{ s / 1 min})} = 39.1 \text{ W}$$

**OQ8.8** Answer (d). The energy is internal energy. Energy is never "used up." The ball finally has no elevation and no compression, so the ball-Earth system has no potential energy. There is no stove, so no energy is put in by heat. The amount of energy transferred away by sound is minuscule.

**OQ8.9** Answer (c). Gravitational energy is proportional to the mass of the object in the Earth's field.

## ANSWERS TO CONCEPTUAL QUESTIONS

**CQ8.1** (a) No. They will not agree on the original gravitational energy if they make different $y = 0$ choices. (b) Yes, (c) Yes. They see the same change in elevation and the same speed, so they do agree on the change in gravitational energy and on the kinetic energy.

**CQ8.2** The larger engine is unnecessary. Consider a 30-minute commute. If you travel the same speed in each car, it will take the same amount of time, expending the same amount of energy. The extra power available from the larger engine isn't used.

**CQ8.3** Unless an object is cooled to absolute zero, then that object will have internal energy, as temperature is a measure of the energy content of matter. Potential energy is not measured for single objects, but for systems. For example, a system comprised of a ball and the Earth will have potential energy, but the ball itself can never be said to have potential energy. An object can have zero kinetic energy, but this measurement is dependent on the reference frame of the observer.

**CQ8.4** All the energy is supplied by foodstuffs that gained their energy from the Sun.

**CQ8.5** (a) The total energy of the ball-Earth system is conserved. Since the system initially has gravitational energy *mgh* and no kinetic energy, the ball will again have zero kinetic energy when it returns to its original position. Air resistance will cause the ball to come back to a point slightly below its initial position. (b) If she gives a forward push to the ball from its starting position, the ball will have the same kinetic energy, and therefore the same speed, at its return: the demonstrator will have to duck.

**CQ8.6** Yes, if it is exerted by an object that is moving in our frame of reference. The flat bed of a truck exerts a static friction force to start a pumpkin moving forward as it slowly starts up.

**CQ8.7**
(a) original elastic potential energy into final kinetic energy

(b) original chemical energy into final internal energy

(c) original chemical potential energy in the batteries into final internal energy, plus a tiny bit of outgoing energy transmitted by mechanical waves

(d) original kinetic energy into final internal energy in the brakes

(e) energy input by heat from the lower layers of the Sun, into energy transmitted by electromagnetic radiation

(f) original chemical energy into final gravitational energy

**CQ8.8** (a) (**i**) A campfire converts chemical energy into internal energy, within the system wood-plus-oxygen, and before energy is transferred by heat and electromagnetic radiation into the surroundings. If all the fuel burns, the process can be 100% efficient.

(**ii**) Chemical-energy-into-internal-energy is also the conversion as iron rusts, and it is the main conversion in mammalian metabolism.

(b) (**i**) An escalator motor converts electrically transmitted energy into gravitational energy. As the system we may choose motor-plus-escalator-and-riders. The efficiency could be, say 90%, but in many escalators a significant amount of internal energy is generated and leaves the system by heat.

(**ii**) A natural process, such as atmospheric electric current in a lightning bolt, which raises the temperature of a particular region of air so that the surrounding air buoys it up, could produce the same electricity-to-gravitational energy conversion with low efficiency.

(c) (**i**) A diver jumps up from a diving board, setting it vibrating temporarily. The material in the board rises in temperature slightly as the visible vibration dies down, and then the board cools off to the constant temperature of the environment. This process for the board-plus-air system can have 100% efficiency in converting the energy of vibration into energy transferred by heat. The energy of vibration is all elastic energy at instants when the board is momentarily at rest at turning points in its motion.

(**ii**) For a natural process, you could think of the branch of a palm tree vibrating for a while after a coconut falls from it.

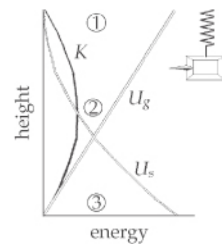
(d) (**i**) Some of the energy transferred by sound in a shout results in kinetic energy of a listener's eardrum; most of the mechanical-wave energy becomes internal energy as the sound is absorbed by all the surfaces it falls upon.

(**ii**) We would also assign low efficiency to a train of water waves doing work to shift sand back and forth in a region near a beach.

(e) (**i**) A demonstration solar car takes in electromagnetic-wave energy in sunlight and turns some fraction of it temporarily into the car's kinetic energy. A much larger fraction becomes internal energy in the solar cells, battery, motor, and air pushed aside.

(**ii**) Perhaps with somewhat higher net efficiency, the pressure of light from a newborn star pushes away gas and dust in the nebula surrounding it.

**CQ8.9** The figure illustrates the relative amounts of the forms of energy in the cycle of the block, where the vertical axis shows position (height) and the horizontal axis shows energy. Let the gravitational energy ($U_g$) be zero for the configuration of the system when the block is at the lowest point in the motion, point (3). After the block moves downward through position (2), where its kinetic energy ($K$) is a maximum, its kinetic energy converts into extra elastic potential energy in the spring ($U_s$). After the block starts moving up at its lower turning point (3), this energy becomes both kinetic energy and gravitational potential energy, and then just gravitational energy when the block is at its greatest height (1) where its elastic potential energy is the least. The energy then turns back into kinetic and elastic potential energy as the block descends, and the cycle repeats.




**ANS. FIG. CQ8.9**

**CQ8.10** Lift a book from a low shelf to place it on a high shelf. The net change in its kinetic energy is zero, but the book-Earth system increases in gravitational potential energy. Stretch a rubber band to encompass the ends of a ruler. It increases in elastic energy. Rub your hands together or let a pearl drift down at constant speed in a bottle of shampoo. Each system (two hands; pearl and shampoo) increases in internal energy.

## SOLUTIONS TO END-OF-CHAPTER PROBLEMS

### Section 8.1 Analysis Model: Nonisolated system (Energy)

**P8.1** (a) The toaster coils take in energy by electrical transmission. They increase in internal energy and put out energy by heat into the air and energy by electromagnetic radiation as they start to glow.

$$\boxed{\Delta E_{\text{int}} = Q + T_{\text{ET}} + T_{\text{ER}}}$$

(b) The car takes in energy by matter transfer. Its fund of chemical potential energy increases. As it moves, its kinetic energy increases and it puts out energy by work on the air, energy by heat in the exhaust, and a tiny bit of energy by mechanical waves in sound.

$$\boxed{\Delta K + \Delta U + \Delta E_{\text{int}} = W + Q + T_{\text{MW}} + T_{\text{MT}}}$$

(c) You take in energy by matter transfer. Your fund of chemical potential energy increases. You are always putting out energy by heat into the surrounding air.

$$\boxed{\Delta U = Q + T_{\text{MT}}}$$

(d) Your house is in steady state, keeping constant energy as it takes in energy by electrical transmission to run the clocks and, we assume, an air conditioner. It absorbs sunlight, taking in energy by electromagnetic radiation. Energy enters the house by matter transfer in the form of natural gas being piped into the home for clothes dryers, water heaters, and stoves. Matter transfer also occurs by means of leaks of air through doors and windows.

$$\boxed{0 = Q + T_{\text{MT}} + T_{\text{ET}} + T_{\text{ER}}}$$

**P8.2** (a) The system of the ball and the Earth is isolated. The gravitational energy of the system decreases as the kinetic energy increases.

$$\boxed{\Delta K + \Delta U = 0}$$

$$\left(\frac{1}{2}mv^2 - 0\right) + \left(-mgh - 0\right) = 0 \to \frac{1}{2}mv^2 = mgy$$

$$\boxed{v = \sqrt{2gh}}$$

(b) The gravity force does positive work on the ball as the ball moves downward. The Earth is assumed to remain stationary, so no work is done on it.

$$\Delta K = W$$

$$\left(\frac{1}{2}mv^2 - 0\right) = mgh \to \frac{1}{2}mv^2 = mgy$$

$$\boxed{v = \sqrt{2gh}}$$

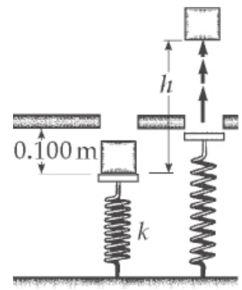
## Section 8.2 Analysis Model: Isolated system (Energy)

**P8.3** From conservation of energy for the block-spring-Earth system,

$$U_{gf} = U_{si}$$

or

$$(0.250\text{ kg})(9.80\text{ m/s}^2)h = \left(\frac{1}{2}\right)(5\,000\text{ N/m})(0.100\text{ m})^2$$




**ANS. FIG. P8.3**

This gives a maximum height, $h = \boxed{10.2\text{ m}}$.

**P8.4** (a) $\Delta K + \Delta U = 0 \rightarrow \Delta K = -\Delta U$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = -\left(mgy_f - mgy_i\right)$$

$$\frac{1}{2}mv_i^2 = \frac{1}{2}mv_i^2 + mgy_f$$

We use the Pythagorean theorem to express the original kinetic energy in terms of the velocity components (kinetic energy itself does not have components):

$$\left(\frac{1}{2}mv_{xi}^2 + \frac{1}{2}mv_{yi}^2\right) = \left(\frac{1}{2}mv_{xf}^2 + 0\right) + mgy_f$$

$$\frac{1}{2}mv_{xi}^2 + \frac{1}{2}mv_{yi}^2 = \frac{1}{2}mv_{xf}^2 + mgy_f$$

Because $v_{xi} = v_{xf}$, we have

$$\frac{1}{2}mv_{yi}^2 = mgy_f \rightarrow y_f = \frac{v_{yi}^2}{2g}$$

so for the first ball:

$$y_f = \frac{v_{yi}^2}{2g} = \frac{\left[(1\,000\text{ m/s})\sin 37.0°\right]^2}{2\left(9.80\text{ m/s}^2\right)} = \boxed{1.85 \times 10^4\text{ m}}$$

and for the second,

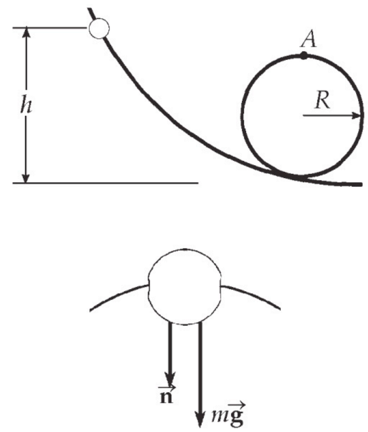
$$y_f = \frac{(1\,000\text{ m/s})^2}{2\left(9.80\text{ m/s}^2\right)} = \boxed{5.10 \times 10^4\text{ m}}$$

(b) The total energy of each ball-Earth system is constant with value

$$E_{\text{mech}} = K_i + U_i = K_i + 0$$

$$E_{\text{mech}} = \frac{1}{2}(20.0\text{ kg})(1\,000\text{ m/s})^2 = \boxed{1.00\times10^7\text{ J}}$$

**P8.5** The speed at the top can be found from the conservation of energy for the bead-track-Earth system, and the normal force can be found from Newton's second law.




**ANS. FIG. P8.5**

(a) We define the bottom of the loop as the zero level for the gravitational potential energy.

Since $v_i = 0$,

$$E_i = K_i + U_i = 0 + mgh = mg(3.50R)$$

The total energy of the bead at point Ⓐ can be written as

$$E_A = K_A + U_A = \frac{1}{2}mv_A^2 + mg(2R)$$

Since mechanical energy is conserved, $E_i = E_A$, we get

$$mg(3.50R) = \frac{1}{2}mv_A^2 + mg(2R)$$

simplifying,

$$v_A^2 = 3.00\,gR$$

$$\boxed{v_A = \sqrt{3.00gR}}$$

(b) To find the normal force at the top, we construct a force diagram as shown, where we assume that $n$ is downward, like $mg$. Newton's second law gives $\sum F = ma_c$, where $a_c$ is the centripetal acceleration.

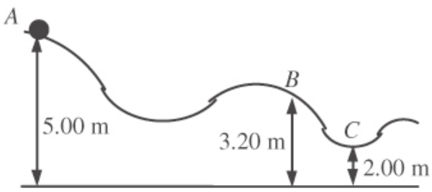
$$\sum F_y = ma_y: \quad n + mg = \frac{mv^2}{r}$$

$$n = m\left[\frac{v^2}{R} - g\right] = m\left[\frac{3.00gR}{R} - g\right] = 2.00mg$$

$$n = 2.00(5.00\times10^{-3}\text{ kg})(9.80\text{ m/s}^2)$$

$$= \boxed{0.098\,0\text{ N downward}}$$

**P8.6** (a) Define the system as the block and the Earth.




ANS. FIG. P8.6

$$\Delta K + \Delta U = 0$$

$$\left(\frac{1}{2}mv_B^2 - 0\right) + \left(mgh_B - mgh_A\right) = 0$$

$$\frac{1}{2}mv_B^2 = mg\left(h_A - h_B\right)$$

$$v_B = \sqrt{2g\left(h_A - h_B\right)}$$

$$v_B = \sqrt{2\left(9.80\text{ m/s}^2\right)\left(5.00\text{ m} - 3.20\text{ m}\right)} = \boxed{5.94\text{ m/s}}$$

Similarly,

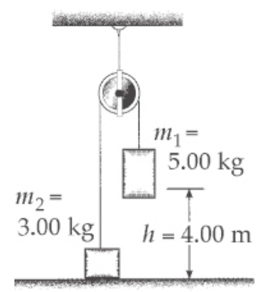
$$v_C = \sqrt{2g\left(h_A - h_C\right)}$$

$$v_C = \sqrt{2g\left(5.00 - 2.00\right)} = \boxed{7.67\text{ m/s}}$$

(b) Treating the block as the system,

$$W_g\Big|_{A\to C} = \Delta K = \frac{1}{2}mv_C^2 - 0 = \frac{1}{2}\left(5.00\text{ kg}\right)\left(7.67\text{ m/s}\right)^2 = \boxed{147\text{ J}}$$

**P8.7** We assign height $y = 0$ to the table top. Using conservation of energy for the system of the Earth and the two objects:




ANS. FIG. P8.7

(a) Choose the initial point before release and the final point, which we code with the subscript *fa*, just before the larger object hits the floor. No external forces do work on the system and no friction acts within the system. Then total mechanical energy of the system remains constant and the energy version of the isolated system model gives

$$(K_A + K_B + U_g)_i = (K_A + K_B + U_g)_{fa}$$

At the initial point, $K_{Ai}$ and $K_{Bi}$ are zero and we define the gravitational potential energy of the system as zero. Thus the total initial energy is zero, and we have

$$0 = \frac{1}{2}(m_1 + m_2)v_{fa}^2 + m_2gh + m_1g(-h)$$

Here we have used the fact that because the cord does not stretch, the two blocks have the same speed. The heavier mass moves down, losing gravitational potential energy, as the lighter mass moves up, gaining gravitational potential energy. Simplifying,

$$(m_1 - m_2)gh = \frac{1}{2}(m_1 + m_2)v_{fa}^2$$

$$v_{fa} = \sqrt{\frac{2(m_1 - m_2)gh}{(m_1 + m_2)}} = \sqrt{\frac{2(5.00\text{ kg} - 3.00\text{ kg})g(4.00\text{ m})}{(5.00\text{ kg} + 3.00\text{ kg})}}$$

$$= \sqrt{19.6}\text{ m/s} = \boxed{4.43\text{ m/s}}$$

(b) Now we apply conservation of energy for the system of the 3.00-kg object and the Earth during the time interval between the instant when the string goes slack and the instant at which the 3.00-kg object reaches its highest position in its free fall.

$$\Delta K + \Delta U = 0 \quad \rightarrow \quad \Delta K = -\Delta U$$

$$0 - \frac{1}{2}m_2 v^2 = -m_2 g \Delta y \rightarrow \Delta y = \frac{v^2}{2g}$$

$$\Delta y = 1.00\text{ m}$$

$$y_{\max} = 4.00\text{ m} + \Delta y = \boxed{5.00\text{ m}}$$

**P8.8** We assume $m_1 > m_2$. We assign height $y = 0$ to the table top.

(a) $\Delta K + \Delta U = 0$

$$\Delta K_1 + \Delta K_2 + \Delta U_1 + \Delta U_2 = 0$$

$$\left[\frac{1}{2}m_1 v^2 - 0\right] + \left[\frac{1}{2}m_2 v^2 - 0\right] + (0 - m_1 gh) + (m_2 gh - 0) = 0$$

$$\frac{1}{2}(m_1 + m_2)v^2 = m_1 gh - m_2 gh = (m_1 - m_2)gh$$

$$v = \boxed{\sqrt{\frac{2(m_1 - m_2)gh}{m_1 + m_2}}}$$

(b) We apply conservation of energy for the system of mass $m_2$ and the Earth during the time interval between the instant when the string goes slack and the instant mass $m_2$ reaches its highest position in its free fall.

$$\Delta K + \Delta U = 0 \quad \rightarrow \quad \Delta K = -\Delta U$$

$$0 - \frac{1}{2}m_2 v^2 = -m_2 g\,\Delta y \rightarrow \Delta y = \frac{v^2}{2g}$$

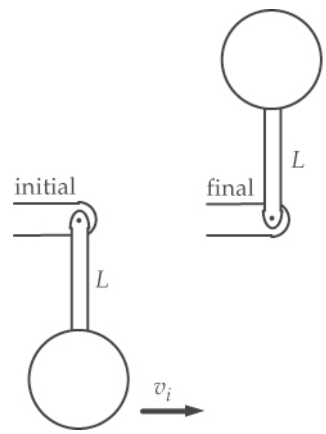
The maximum height of the block is then

$$y_{\max} = h + \Delta y = h + \frac{2(m_1 - m_2)gh}{2g(m_1 + m_2)} = h + \frac{(m_1 - m_2)h}{m_1 + m_2}$$

$$y_{\max} = \frac{(m_1 + m_2)h}{m_1 + m_2} + \frac{(m_1 - m_2)h}{m_1 + m_2}$$

$$y_{\max} = \boxed{\frac{2m_1 h}{m_1 + m_2}}$$

**P8.9** The force of tension and subsequent force of compression in the rod do no work on the ball, since they are perpendicular to each step of displacement. Consider energy conservation of the ball-Earth system between the instant just after you strike the ball and the instant when it reaches the top. The speed at the top is zero if you hit it just hard enough to get it there. We ignore the mass of the "light" rod.




**ANS. FIG. P8.9**

$\Delta K + \Delta U = 0$:

$$\left(0 - \frac{1}{2}mv_i^2\right) + \left[mg(2L) - 0\right] = 0$$

$$v_i = \sqrt{4gL} = \sqrt{4(9.80 \text{ m/s}^2)(0.770 \text{ m})}$$

$$v_i = \boxed{5.49 \text{ m/s}}$$

**P8.10** (a) One child in one jump converts chemical energy into mechanical energy in the amount that the child-Earth system has as gravitational energy when she is at the top of her jump:

$$mgy = (36 \text{ kg})(9.80 \text{ m/s}^2)\,(0.25 \text{ m}) = 88.2 \text{ J}$$

For all of the jumps of the children the energy is

$$12(1.05 \times 10^6)(88.2 \text{ J}) = \boxed{1.11 \times 10^9 \text{ J}}$$

(b) The seismic energy is modeled as

$$E = \left(\frac{0.01}{100}\right)(1.11 \times 10^9 \text{ J}) = 1.11 \times 10^5 \text{ J}$$

making the Richter magnitude

$$\frac{\log E - 4.8}{1.5} = \frac{\log(1.11 \times 10^5) - 4.8}{1.5} = \frac{5.05 - 4.8}{1.5} = \boxed{0.2}$$

**P8.11** When block B moves up by 1 cm, block A moves down by 2 cm and the separation becomes 3 cm. We then choose the final point to be when B has moved up by $\frac{h}{3}$ and has speed $\frac{v_A}{2}$. Then A has moved down $\frac{2h}{3}$ and has speed $v_A$:

$$\Delta K + \Delta U = 0$$

$$\left(K_A + K_B + U_g\right)_f - \left(K_A + K_B + U_g\right)_i = 0$$

$$\left(K_A + K_B + U_g\right)_i = \left(K_A + K_B + U_g\right)_f$$

$$0 + 0 + 0 = \frac{1}{2}mv_A^2 + \frac{1}{2}m\left(\frac{v_A}{2}\right)^2 + \frac{mgh}{3} - \frac{mg2h}{3}$$

$$\frac{mgh}{3} = \frac{5}{8}mv_A^2$$

$$\boxed{v_A = \sqrt{\frac{8gh}{15}}}$$

---

## Section 8.3 Situations Involving Kinetic Friction

**P8.12** We could solve this problem using Newton's second law, but we will use the nonisolated system energy model, here written as $-f_k d = K_f - K_i$, where the kinetic energy change of the sled after the kick results only from the friction between the sled and ice. The weight and normal force both act at 90° to the motion, and therefore do no work on the sled. The friction force is

$$f_k = \mu_k n = \mu_k mg$$

Since the final kinetic energy is zero, we have

$$-f_k d = -K_i$$

or

$$\frac{1}{2}mv_i^2 = \mu_k mgd$$

Thus,

$$d = \frac{mv_i^2}{2f_k} = \frac{mv_i^2}{2\mu_k mg} = \frac{v_i^2}{2\mu_k g} = \frac{(2.00\text{ m/s})^2}{2(0.100)\left(9.80\text{ m/s}^2\right)} = \boxed{2.04\text{ m}}$$

**P8.13** We use the nonisolated system energy model, here written as $-f_k d = K_f - K_i$, where the kinetic energy change of the sled after the kick results only from the friction between the sled and ice.

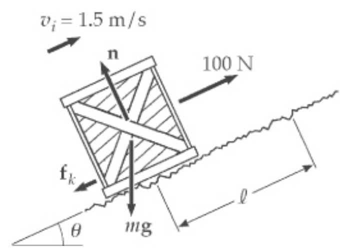
$$\Delta K + \Delta U = -f_k d:$$

$$0 - \frac{1}{2}mv^2 = -f_k d$$

$$\frac{1}{2}mv^2 = \mu_k mgd$$

which gives $\boxed{d = \dfrac{v^2}{2\mu_k g}}$

**P8.14** (a) The force of gravitation is




$$(10.0\text{ kg})(9.80\text{ m/s}^2) = 98.0\text{ N}$$

straight down, at an angle of

$$(90.0° + 20.0°) = 110.0°$$

with the motion. The work done by the gravitational force on the crate is

$$W_g = \vec{\mathbf{F}}\cdot\Delta\vec{\mathbf{r}} = mg\ell\cos(90.0° + \theta)$$

$$= (98.0\text{ N})(5.00\text{ m})\cos 110.0° = \boxed{-168\text{ J}}$$

(b) We set the $x$ and $y$ axes parallel and perpendicular to the incline, respectively.

From $\sum F_y = ma_y$, we have

$$n - (98.0\text{ N})\cos 20.0° = 0$$

so $n = 92.1\text{ N}$

and

$$f_k = \mu_k n = 0.400\,(92.1\text{ N}) = 36.8\text{ N}$$

Therefore,

$$\Delta E_{\text{int}} = f_k d = (36.8\text{ N})(5.00\text{ m}) = \boxed{184\text{ J}}$$

(c) $W_F = F\ell = (100\text{ N})(5.00\text{ m}) = \boxed{500\text{ J}}$

(d) We use the energy version of the nonisolated system model.

$$\Delta K = -f_k d + \sum W_{\text{other forces}}$$

$$\Delta K = -f_k d + W_g + W_{\text{applied force}} + W_n$$

The normal force does zero work, because it is at 90° to the motion.

$$\Delta K = -184\text{ J} - 168\text{ J} + 500\text{ J} + 0 = \boxed{148\text{ J}}$$

(e) Again, $K_f - K_i = -f_k d + \sum W_{\text{other forces}}$, so

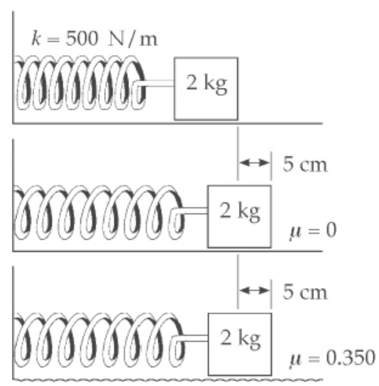
$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \sum W_{\text{other forces}} - f_k d$$

$$v_f = \sqrt{\frac{2}{m}\left[\Delta K + \frac{1}{2}mv_i^2\right]}$$

$$= \sqrt{\left(\frac{2}{10.0\text{ kg}}\right)[148\text{ J} + \frac{1}{2}(10.0\text{ kg})(1.50\text{ m/s})^2]}$$

$$v_f = \sqrt{\frac{2(159\text{ kg}\cdot\text{m}^2/\text{s}^2)}{10.0\text{ kg}}} = \boxed{5.65\text{ m/s}}$$

**P8.15** (a) The spring does positive work on the block:




**ANS. FIG. P8.15**

$$W_s = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$$

$$W_s = \frac{1}{2}(500\text{ N/m})(5.00\times10^{-2}\text{ m})^2 - 0$$

$$= 0.625\text{ J}$$

Applying $\Delta K = W_s$:

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = W_s \rightarrow \frac{1}{2}mv_f^2 - 0 = W_s$$

so

$$v_f = \sqrt{\frac{2(W_s)}{m}}$$

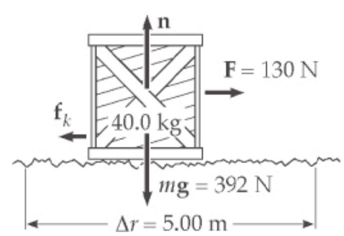
$$= \sqrt{\frac{2(0.625)}{2.00}}\text{ m/s} = \boxed{0.791\text{ m/s}}$$

(b) Now friction results in an increase in internal energy $f_k d$ of the block-surface system. From conservation of energy for a nonisolated system,

$$W_s = \Delta K + \Delta E_{\text{int}}$$
$$\Delta K = W_s - f_k d$$
$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = W_s - f_k d = W_s - \mu_s mgd$$
$$\frac{1}{2}mv_f^2 = 0.625\text{ J} - (0.350)(2.00\text{ kg})(9.80\text{ m/s}^2)(0.050\,0\text{ m})$$
$$\frac{1}{2}(2.00\text{ kg})v_f^2 = 0.625\text{ J} - 0.343\text{ J} = 0.282\text{ J}$$
$$v_f = \sqrt{\frac{2(0.282)}{2.00}}\text{ m/s} = \boxed{0.531\text{ m/s}}$$

**P8.16** $\sum F_y = ma_y$: $n - 392\text{ N} = 0$

$$n = 392\text{ N}$$
$$f_k = \mu_k n = (0.300)(392\text{ N}) = 118\text{ N}$$




**ANS. FIG. P8.16**

(a) The applied force and the motion are both horizontal.

$$W_F = Fd\cos\theta = (130\text{ N})(5.00\text{ m})\cos 0° = \boxed{650\text{ J}}$$

(b) $\Delta E_{\text{int}} = f_k d = (118\text{ N})(5.00\text{ m}) = \boxed{588\text{ J}}$

(c) Since the normal force is perpendicular to the motion,

$$W_n = nd\cos\theta = (392\text{ N})(5.00\text{ m})\cos 90° = \boxed{0}$$

(d) The gravitational force is also perpendicular to the motion, so

$$W_g = mgd\cos\theta = (392\text{ N})(5.00\text{ m})\cos(-90°) = \boxed{0}$$

(e) We write the energy version of the nonisolated system model as

$$\Delta K = K_f - K_i = \sum W_{\text{other}} - \Delta E_{\text{int}}$$
$$\frac{1}{2}mv_f^2 - 0 = 650\text{ J} - 588\text{ J} + 0 + 0 = \boxed{62.0\text{ J}}$$

(f) $v_f = \sqrt{\frac{2K_f}{m}} = \sqrt{\frac{2(62.0\text{ J})}{40.0\text{ kg}}} = \boxed{1.76\text{ m/s}}$

**P8.17** (a) $\Delta E_{\text{int}} = -\Delta K = -\frac{1}{2}m\left(v_f^2 - v_i^2\right)$:

$$\Delta E_{\text{int}} = -\frac{1}{2}(0.400\text{ kg})\left[(6.00)^2 - (8.00)^2\right](\text{m/s})^2 = \boxed{5.60\text{ J}}$$

(b) After $N$ revolutions, the object comes to rest and $K_f = 0$. Thus,

$$\Delta E_{\text{int}} = -\Delta K$$

$$f_k d = -(0 - K_i) = \frac{1}{2}mv_i^2$$

or

$$\mu_k mg\left[N(2\pi r)\right] = \frac{1}{2}mv_i^2$$

This gives

$$N = \frac{\frac{1}{2}mv_i^2}{\mu_k mg(2\pi r)} = \frac{\frac{1}{2}(8.00\text{ m/s})^2}{(0.152)\left(9.80\text{ m/s}^2\right)2\pi(1.50\text{ m})}$$

$$= \boxed{2.28\text{ rev}}$$

## Section 8.4 Changes in Mechanical Energy for Nonconservative Forces

**P8.18** (a) If only conservative forces act, then the total mechanical energy does not change.

$$\Delta K + \Delta U = 0 \quad \text{or} \quad U_f = K_i - K_f + U_i$$

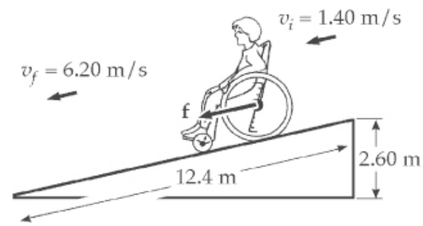
$$U_f = 30.0\text{ J} - 18.0\text{ J} + 10.0\text{ J} = \boxed{22.0\text{ J}}$$

$$E = K + U = 30.0\text{ J} + 10.0\text{ J} = \boxed{40.0\text{ J}}$$

(b) $\boxed{\text{Yes}}$, if the potential energy is less than 22.0 J.

(c) If the potential energy is 5.00 J, the total mechanical energy is $E = K + U = 18.0\text{ J} + 5.00\text{ J} = 23.0\text{ J}$, less than the original 40.0 J. The total mechanical energy has decreased, so a nonconservative force must have acted.

**P8.19** The boy converts some chemical energy in his body into mechanical energy of the boy-chair-Earth system. During this conversion, the energy can be measured as the work his hands do on the wheels.




**ANS. FIG. P8.19**

$$\Delta K + \Delta U + \Delta U_{\text{body}} = -f_k d$$

$$\left(K_f - K_i\right) + \left(U_f - U_i\right) + \Delta U_{\text{body}} = -f_k d$$

$$K_i + U_i + W_{\text{hands-on-wheels}} - f_k d = K_f$$

Rearranging and renaming, we have

$$\frac{1}{2}mv_i^2 + mgy_i + W_{\text{by boy}} - f_k d = \frac{1}{2}mv_f^2$$

$$W_{\text{by boy}} = \frac{1}{2}m\left(v_f^2 - v_i^2\right) - mgy_i + f_k d$$

$$W_{\text{by boy}} = \frac{1}{2}(47.0\text{ kg})\left[(6.20\text{ m/s})^2 - (1.40\text{ m/s})^2\right] - (47.0\text{ kg})\left(9.80\text{ m/s}^2\right)(2.60\text{ m}) + (41.0\text{ N})(12.4\text{ m})$$

$$W_{\text{by boy}} = \boxed{168\text{ J}}$$

**P8.20** (a) Apply conservation of energy to the bead-string-Earth system to find the speed of the bead at Ⓑ. Friction transforms mechanical energy of the system into internal energy $\Delta E_{\text{int}} = f_k d$.

$$\Delta K + \Delta U + \Delta E_{\text{int}} = 0$$

$$\left[\frac{1}{2}mv_B^2 - \frac{1}{2}mv_A^2\right] + \left(mgy_B - mgy_A\right) + f_k d = 0$$

$$\left[\frac{1}{2}mv_B^2 - 0\right] + \left(0 - mgy_A\right) + f_k d = 0 \to \frac{1}{2}mv_B^2 = mgy_A - f_k d$$

$$v_B = \sqrt{2gy_A - \frac{2f_k d}{m}}$$

For $y_A = 0.200$ m, $f_k = 0.025$ N, $d = 0.600$ m, and $m = 25.0 \times 10^{-3}$ kg:

$$v_B = \sqrt{2\left(9.80\text{ m/s}^2\right)(0.200\text{ m}) - \frac{2(0.025\text{ N})(0.600\text{ m})}{25.0\times 10^{-3}\text{ kg}}}$$

$$= \sqrt{2.72}\text{ m/s}$$

$$\boxed{v_B = 1.65\text{ m/s}}$$

(b) The red bead slides a greater distance along the curved path, so friction transforms more of the mechanical energy of the system into internal energy. There is less of the system's original potential energy in the form of kinetic energy when the bead arrives at point Ⓑ. The result is that the green bead arrives at point Ⓑ first and at higher speed.

**P8.21** Use Equation 8.16: $\Delta E_{\text{mech}} = \Delta K + \Delta U = -f_k d$

$$\left(K_f - K_i\right) + \left(U_f - U_i\right) = -f_k d$$

$$K_i + U_i - f_k d = K_f + U_f$$

(a) $K_i + U_i - f_k d = K_f + U_f$

$$0 + \frac{1}{2}kx^2 - f\Delta x = \frac{1}{2}mv^2 + 0$$

$$\frac{1}{2}(8.00\text{ N/m})\left(5.00\times 10^{-2}\text{ m}\right)^2 - \left(3.20\times 10^{-2}\text{ N}\right)(0.150\text{ m}) = \frac{1}{2}\left(5.30\times 10^{-3}\text{ kg}\right)v^2$$

$$v = \sqrt{\frac{2\left(5.20\times 10^{-3}\text{ J}\right)}{5.30\times 10^{-3}\text{ kg}}} = \boxed{1.40\text{ m/s}}$$

(b) When the spring force just equals the friction force, the ball will stop speeding up. Here $\left|\vec{F}_s\right| = kx$; the spring is compressed by

$$\frac{3.20\times 10^{-2}\text{ N}}{8.00\text{ N/m}} = 0.400\text{ cm}$$

and the ball has moved

$$5.00\text{ cm} - 0.400\text{ cm} = \boxed{4.60\text{ cm from the start}}$$

(c) Between start and maximum speed points,

$$\frac{1}{2}kx_i^2 - f\Delta x = \frac{1}{2}mv^2 + \frac{1}{2}kx_f^2$$

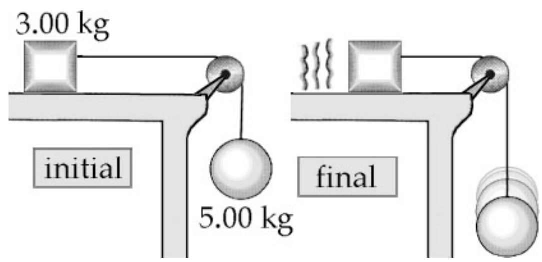
$$\frac{1}{2}(8.00\text{ N/m})\left(5.00\times 10^{-2}\text{ m}\right)^2 - \left(3.20\times 10^{-2}\text{ N}\right)\left(4.60\times 10^{-2}\text{ m}\right)$$

$$= \frac{1}{2}\left(5.30\times 10^{-3}\text{ kg}\right)v^2 + \frac{1}{2}(8.00\text{ N/m})\left(4.00\times 10^{-3}\text{ m}\right)^2$$

$$v = \boxed{1.79\text{ m/s}}$$

**P8.22** For the Earth plus objects 1 (block) and 2 (ball), we write the energy model equation as

$$(K_1 + K_2 + U_1 + U_2)_f - (K_1 + K_2 + U_1 + U_2)_i = \sum W_{\text{other forces}} - f_k d$$




**ANS. FIG. P8.22**

Choose the initial point before release and the final point after each block has moved 1.50 m. Choose $U = 0$ with the 3.00-kg block on the tabletop and the 5.00-kg block in its final position.

So $\quad K_{1i} = K_{2i} = U_{1i} = U_{1f} = U_{2f} = 0$

We have chosen to include the Earth in our system, so gravitation is an internal force. Because the only external forces are friction and normal forces exerted by the table and the pulley at right angles to the motion,

$$\sum W_{\text{other forces}} = 0$$

We now have

$$\frac{1}{2}m_1 v_f^2 + \frac{1}{2}m_2 v_f^2 + 0 + 0 - 0 - 0 - 0 - m_2 g y_{2i} = 0 - f_k d$$

where the friction force is

$$f_k = \mu_k n = \mu_k m_A g$$

The friction force causes a negative change in mechanical energy because the force opposes the motion. Since all of the variables are known except for $v_f$, we can substitute and solve for the final speed.

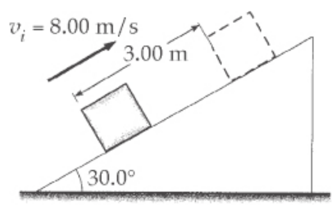
$$\frac{1}{2}m_1 v_f^2 + \frac{1}{2}m_2 v_f^2 - m_2 g y_{2i} = -f_k d$$

$$v^2 = \frac{2gh(m_2 - \mu_k m_1)}{m_1 + m_2}$$

$$v = \sqrt{\frac{2(9.80\ \text{m/s}^2)(1.50\ \text{m})[5.00\ \text{kg} - 0.400(3.00\ \text{kg})]}{8.00\ \text{kg}}}$$

$$= \boxed{3.74\ \text{m/s}}$$

**P8.23** We consider the block-plane-planet system between an initial point just after the block has been given its shove and a final point when the block comes to rest.




**ANS. FIG. P8.23**

(a) The change in kinetic energy is

$$\Delta K = K_f - K_i = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$
$$= 0 - \frac{1}{2}(5.00\text{ kg})(8.00\text{ m/s})^2 = \boxed{-160\text{ J}}$$

(b) The change in gravitational potential energy is

$$\Delta U = U_f - U_i = mgh$$
$$= (5.00\text{ kg})(9.80\text{ m/s}^2)(3.00\text{ m})\sin 30.0° = \boxed{73.5\text{ J}}$$

(c) The nonisolated system energy model we write as

$$\Delta K + \Delta U = \sum W_{\text{other forces}} - f_k d = 0 - f_k d$$

The force of friction is the only unknown, so we may find it from

$$f_k = \frac{\Delta K - \Delta U}{d} = \frac{+160\text{ J} - 73.5\text{ J}}{3.00\text{ m}} = \boxed{28.8\text{ N}}$$

(d) The forces perpendicular to the incline must add to zero.

$$\sum F_y = 0: \quad +n - mg\cos 30.0° = 0$$

Evaluating,

$$n = mg\cos 30.0° = (5.00\text{ kg})(9.80\text{ m/s}^2)\cos 30.0° = 42.4\text{ N}$$

Now $f_k = \mu_k n$ gives

$$\mu_k = \frac{f_k}{n} = \frac{28.8\text{ N}}{42.4\text{ N}} = \boxed{0.679}$$

**P8.24** (a) The object drops distance $d$ = 1.20 m until it hits the spring, then it continues until the spring is compressed a distance $x$.

$$\Delta K + \Delta U = 0$$
$$K_f - K_i + U_f - U_i = 0$$
$$0 - 0 + \left(\frac{1}{2}kx^2 - 0\right) + \left[mg(-x) - mgd\right] = 0$$
$$\frac{1}{2}kx^2 - mg(x + d) = 0$$

$$\frac{1}{2}(320\text{ N/m})x^2-(1.50\text{ kg})(9.80\text{ m/s}^2)(x+1.20\text{ m})=0$$

Dropping units, we have

$$160x^2-(14.7)x-17.6=0$$

$$x=\frac{14.7\pm\sqrt{(-14.7)^2-4(160)(-17.6)}}{2(160)}$$

$$x=\frac{14.7\pm 107}{320}$$

The negative root does not apply because $x$ is a distance. We have

$$x=\boxed{0.381\text{ m}}$$

(b) This time, friction acts through distance $(x + d)$ in the object-spring-Earth system:

$$\Delta K+\Delta U=-f_k(x+d)$$

$$0-0+\left(\frac{1}{2}kx^2-0\right)+[mg(-x)-mgd]=-f_k(x+d)$$

$$\frac{1}{2}kx^2-(mg-f_k)x-(mg-f_k)d=0$$

where $mg-f_k = 14.0$ N. Suppressing units, we have

$$160x^2-14.0x-16.8=0$$

$$160x^2-14.0x-16.8=0$$

$$x=\frac{14.0\pm\sqrt{(-14.0)^2-4(160)(-16.8)}}{2(160)}$$

$$x=\frac{14.0\pm 105}{320}$$

The positive root is $x=\boxed{0.371\text{ m.}}$

(c) On the Moon, we have

$$\frac{1}{2}kx^2-mg(x+d)=0$$

$$\frac{1}{2}(320\text{ N/m})x^2-(1.50\text{ kg})(1.63\text{ m/s}^2)(x+1.20\text{ m})=0$$

Suppressing units,

$$160x^2-2.45x-2.93=0$$

$$x = \frac{2.45 \pm \sqrt{(-2.45)^2 - 4(160)(-2.93)}}{2(160)}$$

$$x = \frac{2.45 \pm 43.3}{320}$$

$$x = \boxed{0.143 \text{ m}}$$

**P8.25** The spring is initially compressed by $x_i = 0.100$ m. The block travels up the ramp distance $d$.

The spring does work $W_s = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2 = \frac{1}{2}kx_i^2 - 0 = \frac{1}{2}kx_i^2$ on the block.

Gravity does work $W_g = mgd\cos(90° + 60.0°) = mgd\sin(60.0°)$ on the block. There is no friction.

(a) $\sum W = \Delta K$: $\quad W_s + W_g = 0$

$$\frac{1}{2}kx_i^2 - mgd \ \sin(60.0°) = 0$$

$$\frac{1}{2}(1.40 \times 10^3 \text{ N/m})(0.100 \text{ m})^2 - (0.200 \text{ kg})(9.80 \text{ m/s}^2)d(\sin 60.0°) = 0$$

$$d = \boxed{4.12 \text{ m}}$$

(b) Within the system, friction transforms kinetic energy into internal energy:

$$\Delta E_{\text{int}} = f_k d = (\mu_k n)d = \mu_k(mg \cos 60.0°)d$$

$$\sum W = \Delta K + \Delta E_{\text{int}}: \quad W_s + W_g - \Delta E_{\text{int}} = 0$$

$$\frac{1}{2}kx_i^2 - mgd \sin 60.0° - \mu_k mg \cos 60.0° d = 0$$

$$\frac{1}{2}(1.40 \times 10^3 \text{ N/m})(0.100 \text{ m})^2 - (0.200 \text{ kg})(9.80 \text{ m/s}^2)d(\sin 60.0°) - (0.400)(0.200 \text{ kg})(9.80 \text{ m/s}^2)(\cos 60.0°)d = 0$$

$$d = \boxed{3.35 \text{ m}}$$

**P8.26** Air resistance acts like friction. Consider the whole motion:

$$\Delta K + \Delta U = -f_{\text{air}}d \rightarrow K_i + U_i - f_{\text{air}}d = K_f + U_f$$

(a) $0 + mgy_i - f_1 d_1 - f_2 d_2 = \frac{1}{2}mv_f^2 + 0$

$$(80.0\text{ kg})(9.80\text{ m/s}^2)1\,000\text{ m} - (50.0\text{ N})(800\text{ m}) - (3\,600\text{ N})(200\text{ m}) = \frac{1}{2}(80.0\text{ kg})v_f^2$$

$$784\,000\text{ J} - 40\,000\text{ J} - 720\,000\text{ J} = \frac{1}{2}(80.0\text{ kg})v_f^2$$

$$v_f = \sqrt{\frac{2(24\,000\text{ J})}{80.0\text{ kg}}} = \boxed{24.5\text{ m/s}}$$

(b) Yes. This is too fast for safety.

(c) Now in the same energy equation as in part (a), $d_2$ is unknown, and $d_1 = 1\,000\text{ m} - d_2$:

$$784\,000\text{ J} - (50.0\text{ N})(1\,000\text{ m} - d_2) - (3\,600\text{ N})d_2 = \frac{1}{2}(80.0\text{ kg})(5.00\text{ m/s})^2$$

$$784\,000\text{ J} - 50\,000\text{ J} - (3\,550\text{ N})d_2 = 1\,000\text{ J}$$

$$d_2 = \frac{733\,000\text{ J}}{3\,550\text{ N}} = \boxed{206\text{ m}}$$

(d) The air drag is proportional to the square of the skydiver's speed, so it will change quite a bit, It will be larger than her 784-N weight only after the chute is opened. It will be nearly equal to 784 N before she opens the chute and again before she touches down whenever she moves near terminal speed.

**P8.27** (a) Yes, the child-Earth system is isolated because the only force that can do work on the child is her weight. The normal force from the slide can do no work because it is always perpendicular to her displacement. The slide is frictionless, and we ignore air resistance.

(b) No, because there is no friction.

(c) At the top of the water slide,

$$U_g = mgh \quad \text{and} \quad K = 0: \quad E = 0 + mgh \rightarrow \boxed{E = mgh}$$

(d) At the launch point, her speed is $v_i$, and height $h = h/5$:

$$E = K + U_g$$

$$E = \boxed{\frac{1}{2}mv_i^2 + \frac{mgh}{5}}$$

(e) At her maximum airborne height, $h = y_{\max}$:

$$E = \frac{1}{2}mv^2 + mgh = \frac{1}{2}m({v_{xi}}^2 + {v_{yi}}^2) + mgy_{\max}$$

$$E = \frac{1}{2}m({v_{xi}}^2 + 0) + mgy_{\max} \rightarrow E = \boxed{\frac{1}{2}mv_{xi}^2 + mgy_{\max}}$$

(f) $E = mgh = \frac{1}{2}m{v_i}^2 + mgh/5 \rightarrow \boxed{v_i = \sqrt{\frac{8gh}{5}}}$

(g) At the launch point, her velocity has components $v_{xi} = v_i \cos\theta$ and $v_{yi} = v_i \sin\theta$:

$$E = \frac{1}{2}mv_i^2 + \frac{mgh}{5} = \frac{1}{2}mv_{xi}^2 + mgy_{\max}$$

$$\rightarrow \frac{1}{2}\cancel{m}v_i^2 + \frac{\cancel{m}gh}{5} = \frac{1}{2}\cancel{m}\left(v_i \cos\theta\right)^2 + \cancel{m}gy_{\max}$$

$$\rightarrow \frac{1}{2}v_i^2\left(1 - \cos^2\theta\right) + \frac{gh}{5} = gh_{\max}$$

$$\rightarrow h_{\max} = \frac{1}{2\cancel{g}}\left(\frac{8\cancel{g}h}{5}\right)\left(1 - \cos^2\theta\right) + \frac{\cancel{g}h}{5\cancel{g}}$$

$$\rightarrow h_{\max} = \left(\frac{4h}{5}\right)\left(1 - \cos^2\theta\right) + \frac{h}{5} \rightarrow \boxed{h_{\max} = h\left(1 - \frac{4}{5}\cos^2\theta\right)}$$

(h) No. If friction is present, mechanical energy of the system would *not* be conserved, so her kinetic energy at all points after leaving the top of the waterslide would be reduced when compared with the frictionless case. Consequently, her launch speed, maximum height reached, and final speed would be reduced as well.

## Section 8.5 Power

**P8.28** (a) The moving sewage possesses kinetic energy in the same amount as it enters and leaves the pump. The work of the pump increases the gravitational energy of the sewage-Earth system. We take the equation $K_i + U_{gi} + W_{\text{pump}} = K_f + U_{gf}$, subtract out the $K$ terms, and choose $U_{gi} = 0$ at the bottom of the pump, to obtain $W_{\text{pump}} = mgy_f$. Now we differentiate through with respect to time:

$$P_{\text{pump}} = \frac{\Delta m}{\Delta t} g y_f = \rho \frac{\Delta V}{\Delta t} g y_f$$

$$= \left(1\,050\ \text{kg/m}^3\right)\left(1.89 \times 10^6\ \text{L/d}\right)$$

$$\times \left(\frac{1\ \text{m}^3}{1\,000\ \text{L}}\right)\left(\frac{1\ \text{d}}{86\,400\ \text{s}}\right)\left(\frac{9.80\ \text{m}}{\text{s}^2}\right)(5.49\ \text{m})$$

$$= \boxed{1.24 \times 10^3\ \text{W}}$$

(b) $$\text{efficiency} = \frac{\text{useful output work}}{\text{total input work}} = \frac{\text{useful output work}/\Delta t}{\text{useful input work}/\Delta t}$$

$$= \frac{\text{mechanical output power}}{\text{input electric power}} = \frac{1.24\ \text{kW}}{5.90\ \text{kW}}$$

$$= \boxed{0.209} = 20.9\%$$

The remaining power, 5.90 – 1.24 kW = 4.66 kW, is the rate at which internal energy is injected into the sewage and the surroundings of the pump.

**P8.29** The Marine must exert an 820-N upward force, opposite the gravitational force, to lift his body at constant speed. The Marine's power output is the work he does divided by the time interval:

$$\text{Power} = \frac{W}{t}$$

$$P = \frac{mgh}{t} = \frac{(820\ \text{N})(12.0\ \text{m})}{8.00\ \text{s}} = 1\,230\ \text{W} = \boxed{1.23\ \text{kW}}$$

**P8.30** (a) $$P_{\text{av}} = \frac{W}{\Delta t} = \frac{K_f}{\Delta t} = \frac{mv^2}{2\Delta t} = \frac{(0.875\ \text{kg})(0.620\ \text{m/s})^2}{2\left(21 \times 10^{-3}\ \text{s}\right)} = \boxed{8.01\ \text{W}}$$

(b) Some of the energy transferring into the system of the train goes into internal energy in warmer track and moving parts and some leaves the system by sound. To account for this as well as the stated increase in kinetic energy, energy must be transferred at a rate higher than 8.01 W.

**P8.31** When the car moves at constant speed on a level roadway, the power used to overcome the total friction force equals the power input from the engine, or $P_{\text{output}} = f_{\text{total}}\, v = P_{\text{input}}$. This gives

$$f_{\text{total}} = \frac{P_{\text{input}}}{v} = \frac{175\text{ hp}}{29\text{ m/s}}\left(\frac{746\text{ W}}{1\text{ hp}}\right)$$

$$= 4.5\times10^5\text{ N or about }\boxed{5\times10^5\text{ N.}}$$

**P8.32** Neglecting any variation of gravity with altitude, the work required to lift a $3.20 \times 10^7$ kg load at constant speed to an altitude of $\Delta y = 1.75$ km is

$$W = \Delta PE_g = mg(\Delta y)$$
$$= (3.20\times10^7\text{ kg})(9.80\text{ m/s}^2)(1.75\times10^3\text{ m})$$
$$= 5.49\times10^{11}\text{ J}$$

The time required to do this work using a $P = 2.70$ kW $= 2.70 \times 10^3$ J/s pump is

$$\Delta t = \frac{W}{P} = \frac{5.49\times10^{11}\text{ J}}{2.70\times10^3\text{ J/s}} = \boxed{2.03\times10^8\text{ s}}$$
$$= (2.03\times10^8\text{ s})\left(\frac{1\text{ h}}{3\,600\text{ s}}\right)$$
$$= \boxed{5.64\times10^4\text{ h}} = 6.44\text{ yr}$$

**P8.33** energy = power × time

For the 28.0-W bulb:

Energy used = (28.0 W)($1.00 \times 10^4$ h) = 280 kWh

total cost = \$4.50 + (280 kWh)(\$0.200/kWh) = \$60.50

For the 100-W bulb:

Energy used = (100 W)($1.00 \times 10^4$ h) = $1.00 \times 10^3$ kWh

$$\#\text{ of bulbs used} = \frac{1.00\times10^4\text{ h}}{750\text{ h/bulb}} = 13.3 = 13\text{ bulbs}$$

total cost = 13($0.420) + (1.00 × 10$^3$ kWh)($0.200/kWh) = $205.46

Savings with energy-efficient bulb:

$205.46 – $60.50 = $144.96 = $\boxed{\$\,145}$

**P8.34** The useful output energy is

$$120\ \text{Wh}(1-0.60) = mg\left(y_f - y_i\right) = F\,\Delta y$$

$$\Delta y = \frac{120\ \text{W}(3\ 600\ \text{s})0.40}{890\ \text{N}}\left(\frac{\text{J}}{\text{W}\cdot\text{s}}\right)\left(\frac{\text{N}\cdot\text{m}}{\text{J}}\right) = \boxed{194\ \text{m}}$$

**P8.35** A 1 300-kg car speeds up from rest to 55.0 mi/h = 24.6 m/s in 15.0 s. The output work of the engine is equal to its final kinetic energy,

$$\frac{1}{2}(1\ 300\ \text{kg})(24.6\ \text{m/s})^2 = 390\ \text{kJ}$$

with power $P = \dfrac{390\ 000\ \text{J}}{15.0\ \text{s}}\ \boxed{\sim 10^4\ \text{W},}$ around 30 horsepower.

**P8.36** $P = \dfrac{W}{\Delta t}$

older-model: $W = \dfrac{1}{2}mv^2$

newer-model: $W = \dfrac{1}{2}m(2v)^2 = \dfrac{1}{2}(4mv^2) \quad\rightarrow\quad P_{\text{newer}} = \dfrac{4mv^2}{2\Delta t} = 4\dfrac{mv^2}{2\Delta t}$

$\boxed{\text{The power of the sports car is four times that of the older-model car.}}$

***P8.37** (a) The fuel economy for walking is

$$\frac{1\ \text{h}}{220\ \text{kcal}}\left(\frac{3\ \text{mi}}{\text{h}}\right)\left(\frac{1\ \text{kcal}}{4\ 186\ \text{J}}\right)\left(\frac{1.30\times 10^8\ \text{J}}{1\ \text{gal}}\right) = \boxed{423\ \text{mi/gal}}$$

(b) For bicycling:

$$\frac{1\ \text{h}}{400\ \text{kcal}}\left(\frac{10\ \text{mi}}{\text{h}}\right)\left(\frac{1\ \text{kcal}}{4\ 186\ \text{J}}\right)\left(\frac{1.30\times 10^8\ \text{J}}{1\ \text{gal}}\right) = \boxed{776\ \text{mi/gal}}$$

**P8.38** (a) The distance moved upward in the first 3.00 s is

$$\Delta y = \bar{v}\Delta t = \left[\frac{0+1.75\ \text{m/s}}{2}\right](3.00\ \text{s}) = 2.63\ \text{m}$$

The motor and the Earth's gravity do work on the elevator car:

$$W_{\text{motor}} + W_{\text{gravity}} = \Delta K$$

$$W_{\text{motor}} + (mg\Delta y)\cos 180° = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W_{\text{motor}} - (mg\Delta y) = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W_{\text{motor}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 + mg\Delta y$$

$$W_{\text{motor}} = \frac{1}{2}(650\text{ kg})(1.75\text{ m/s})^2 - 0 + (650\text{ kg})g(2.63\text{ m})$$

$$= 1.77 \times 10^4\text{ J}$$

Also, $W = \bar{P}\Delta t$ so $\bar{P} = \dfrac{W}{\Delta t} = \dfrac{1.77 \times 10^4\text{ J}}{3.00\text{ s}} = \boxed{5.91 \times 10^3\text{ W}} = 7.92\text{ hp}$.

(b) When moving upward at constant speed ($v$ = 1.75 m/s), the applied force equals the weight = (650 kg)(9.80 m/s$^2$) = 6.37 × 10$^3$ N. Therefore,

$$P = Fv = (6.37 \times 10^3\text{ N})(1.75\text{ m/s}) = \boxed{1.11 \times 10^4\text{ W}} = 14.9\text{ hp}$$

**P8.39** As the piano is lifted at constant speed up to the apartment, the total work that must be done on it is

$$W_{\text{nc}} = \Delta K + \Delta U_g = 0 + mg(y_f - y_i)$$

$$= (3.50 \times 10^3\text{ N})(25.0\text{ m})$$

$$= 8.75 \times 10^4\text{ J}$$

The three workmen (using a pulley system with an efficiency of 0.750) do work on the piano at a rate of

$$P_{\text{net}} = 0.750\left(3P_{\substack{\text{single}\\\text{worker}}}\right) = 0.750[3(165\text{ W})] = 371\text{ W} = 371\text{ J/s}$$

so the time required to do the necessary work on the piano is

$$\Delta t = \frac{W_{\text{nc}}}{P_{\text{net}}} = \frac{8.75 \times 10^4\text{ J}}{371\text{ J/s}} = \boxed{236\text{ s}} = (236\text{ s})\left(\frac{1\text{ min}}{60\text{ s}}\right) = \boxed{3.93\text{ min}}$$

**P8.40** (a) Burning 1 kg of fat releases energy

$$1\text{ kg}\left(\frac{1\,000\text{ g}}{1\text{ kg}}\right)\left(\frac{9\text{ kcal}}{1\text{ g}}\right)\left(\frac{4\,186\text{ J}}{1\text{ kcal}}\right) = 3.77 \times 10^7\text{ J}$$

The mechanical energy output is

$$\left(3.77\times10^{7}\text{ J}\right)(0.20) = nFd\cos\theta$$

where $n$ is the number of flights of stairs. Then

$$7.53\times10^{6}\text{ J} = nmg\Delta y\cos 0°$$

$$7.53\times10^{6}\text{ J} = n(75\text{ kg})\left(9.8\text{ m/s}^2\right)(80\text{ steps})(0.150\text{ m})$$

$$7.53\times10^{6}\text{ J} = n\left(8.82\times10^{3}\text{ J}\right)$$

where the number of times she must climb the stairs is

$$n = \frac{7.53\times10^{6}\text{ J}}{8.82\times10^{3}\text{ J}} = \boxed{854}$$

(b) Her mechanical power output is

$$P = \frac{W}{t} = \frac{8.82\times10^{3}\text{ J}}{65\text{ s}} = \boxed{136\text{ W}} = (136\text{ W})\left(\frac{1\text{ hp}}{746\text{ W}}\right)$$

$$= \boxed{0.182\text{ hp}}$$

(c) This method is impractical compared to limiting food intake.

**P8.41** The energy of the car-Earth system is $E = \frac{1}{2}mv^2 + mgy$:

$$E = \frac{1}{2}mv^2 + mgd\sin\theta$$

where $d$ is the distance the car has moved along the track.

$$P = \frac{dE}{dt} = mv\frac{dv}{dt} + mgv\sin\theta$$

(a) When speed is constant,

$$P = mgv\sin\theta = (950\text{ kg})\left(9.80\text{ m/s}^2\right)(2.20\text{ m/s})\sin 30.0°$$

$$= \boxed{1.02\times10^{4}\text{ W}}$$

(b) $$\frac{dv}{dt} = a = \frac{2.20\text{ m/s} - 0}{12\text{ s}} = 0.183\text{ m/s}^2$$

Maximum power is injected just before maximum speed is attained:

$$P = mva + mgv\sin\theta$$

$$= (950\text{ kg})(2.20\text{ m/s})\left(0.183\text{ m/s}^2\right) + 1.02\times10^{4}\text{ W}$$

$$= \boxed{1.06\times10^{4}\text{ W}}$$

(c) At the top end,

$$\frac{1}{2}mv^2 + mgd\sin\theta$$
$$= 950\text{ kg}\left(\frac{1}{2}(2.20\text{ m/s})^2 + (9.80\text{ m/s}^2)(1\,250\text{ m})\sin 30°\right)$$
$$= \boxed{5.82\times 10^6\text{ J}}$$

## Additional Problems

***P8.42** At a pace I could keep up for a half-hour exercise period, I climb two stories up, traversing forty steps each 18 cm high, in 20 s. My output work becomes the final gravitational energy of the system of the Earth and me,

$$mgy = (85\text{ kg})(9.80\text{ m/s}^2)(40\times 0.18\text{ m}) = 6\,000\text{ J}$$

making my sustainable power $\dfrac{6\,000\text{ J}}{20\text{ s}} = \boxed{\sim 10^2\text{ W}}$.

**P8.43** (a) $U_A = mgR = (0.200\text{ kg})(9.80\text{ m/s}^2)(0.300\text{ m}) = \boxed{0.588\text{ J}}$

(b) $K_A + U_A = K_B + U_B$

$K_B = K_A + U_A - U_B = mgR = \boxed{0.588\text{ J}}$

(c) $v_B = \sqrt{\dfrac{2K_B}{m}} = \sqrt{\dfrac{2(0.588\text{ J})}{0.200\text{ kg}}} = \boxed{2.42\text{ m/s}}$

(d) $U_C = mgh_C = (0.200\text{ kg})(9.80\text{ m/s}^2)(0.200\text{ m}) = \boxed{0.392\text{ J}}$

$K_C = K_A + U_A - U_C = mg(h_A - h_C)$
$K_C = (0.200\text{ kg})(9.80\text{ m/s}^2)(0.300 - 0.200)\text{ m} = \boxed{0.196\text{ J}}$

**P8.44** (a) Let us take $U = 0$ for the particle-bowl-Earth system when the particle is at Ⓑ. Since $v_B = 1.50$ m/s and $m = 200$ g,

$$K_B = \frac{1}{2}mv_B^2 = \frac{1}{2}(0.200\text{ kg})(1.50\text{ m/s})^2 = \boxed{0.225\text{ J}}$$

(b) At Ⓐ, $v_i = 0$, $K_A = 0$, and the whole energy at Ⓐ is $U_A = mgR$:

$$E_i = K_A + U_A = 0 + mgR = (0.200\text{ kg})(9.80\text{ m/s}^2)(0.300\text{ m})$$
$$= 0.588\text{ J}$$

At Ⓑ,

$$E_f = K_B + U_B = 0.225\text{ J} + 0$$

The decrease in mechanical energy is equal to the increase in internal energy.

$$E_{\text{mech},\,i} + \Delta E_{\text{int}} = E_{\text{mech},\,f}$$

The energy transformed is

$$\Delta E_{\text{int}} = -\Delta E_{\text{mech}} = E_{\text{mech},\,i} - E_{\text{mech},\,f} = 0.588\text{ J} - 0.225\text{ J} = \boxed{0.363\text{ J}}$$

(c) No.

(d) It is possible to find an effective coefficient of friction, but not the actual value of $\mu$ since $n$ and $f$ vary with position.

**P8.45** Taking $y = 0$ at ground level, and using conservation of energy from when the boy starts from rest ($v_i = 0$) at the top of the slide ($y_i = H$) to the instant he leaves the lower end ($y_f = h$) of the frictionless slide at speed $v$, where his velocity is horizontal ($v_{xf} = v$, $v_{yf} = 0$), we have

$$E_0 = E_{\text{top}} \;\rightarrow\; \frac{1}{2}mv^2 + mgh = 0 + mgH$$

or $$v^2 = 2g(H - h) \qquad \textbf{[1]}$$

Considering his flight as a projectile after leaving the end of the slide,

$$\Delta y = v_{yi}t + \frac{1}{2}a_y t^2$$

gives the time to drop distance $h$ to the ground as

$$-h = 0 + \frac{1}{2}(-g)t^2 \qquad \text{or} \qquad t = \sqrt{\frac{2h}{g}}$$

The horizontal distance traveled (at constant horizontal velocity) during this time is $d$, so

$$d = vt = v\sqrt{\frac{2h}{g}} \qquad \text{and} \qquad v = d\sqrt{\frac{g}{2h}} = \sqrt{\frac{gd^2}{2h}}$$

Substituting this expression for $v$ into equation [1] above gives

$$\frac{gd^2}{2h} = 2g(H - h) \qquad \text{or} \qquad \boxed{H = h + \frac{d^2}{4h}}$$

**P8.46** (a) Mechanical energy is conserved in the two blocks-Earth system:

$$m_2gy = \frac{1}{2}(m_1 + m_2)v^2$$

$$v = \left[\frac{2m_2gy}{m_1 + m_2}\right]^{1/2} = \left[\frac{2(1.90\text{ kg})(9.80\text{ m/s}^2)(0.900\text{ m})}{5.40\text{ kg}}\right]^{1/2}$$

$$= \boxed{2.49\text{ m/s}}$$

(b) For the 3.50-kg block from when the string goes slack until just before the block hits the floor, conservation of energy gives

$$\frac{1}{2}(m_2)v^2 + m_2gy = \frac{1}{2}(m_2)v_d^2$$

$$v_d = \left[2gy + v^2\right]^{1/2} = \left[2(9.80\text{ m/s}^2)(1.20\text{ m}) + (2.49\text{ m/s})^2\right]^{1/2}$$

$$= \boxed{5.45\text{ m/s}}$$

(c) The 3.50-kg block takes this time in flight to the floor: from $y = (1/2)gt^2$ we have $t = [2(1.2)/9.8]^{1/2} = 0.495$ s. Its horizontal component of displacement at impact is then

$$x = v_d t = (2.49\text{ m/s})(0.495\text{ s}) = \boxed{1.23\text{ m}}$$

(d) $\boxed{\text{No.}}$

(e) $\boxed{\text{Some of the kinetic energy of } m_2 \text{ is transferred away as sound and some is transformed to internal energy in } m_1 \text{ and the floor.}}$

**P8.47** (a) Given $m = 4.00$ kg and $x = t + 2.0t^3$, we find the velocity by differentiating:

$$v = \frac{dx}{dt} = \frac{d}{dt}\left(t + 2t^3\right) = 1 + 6t^2$$

Then the kinetic energy from its definition is

$$K = \frac{1}{2}mv^2 = \frac{1}{2}(4.00)\left(1 + 6t^2\right)^2 = \boxed{2 + 24t^2 + 72t^4}$$

where $K$ is in J and $t$ is in s.

(b) Acceleration is the measure of how fast velocity is changing:

$$a = \frac{dv}{dt} = \frac{d}{dt}\left(1 + 6t^2\right) = \boxed{12t}$$

where $a$ is in m/s$^2$ and $t$ is in s.

Newton's second law gives the total force exerted on the particle by the rest of the universe:

$$\sum F = ma = (4.00\text{ kg})(12t) = \boxed{48t}$$

where $F$ is in N and $t$ is in s.

(c) Power is how fast work is done to increase the object's kinetic energy:

$$P = \frac{dW}{dt} = \frac{dK}{dt} = \frac{d}{dt}\left(2.00 + 24t^2 + 72t^4\right) = \boxed{48t + 288t^3}$$

where $P$ is in W [watts] and $t$ is in s.

Alternatively, we could use $P = Fv = 48t(1.00 + 6.0t^2)$.

(d) The work-kinetic energy theorem $\Delta K = \sum W$ lets us find the work done on the object between $t_i = 0$ and $t_f = 2.00$ s. At $t_i = 0$ we have $K_i = 2.00$ J. At $t_f = 2.00$ s, suppressing units,

$$K_f = [2 + 24(2.00\text{ s})^2 + 72(2.00\text{ s})^4] = 1250\text{ J}$$

Therefore the work input is

$$W = K_f - K_i = 1\ 248\text{ J} = \boxed{1.25 \times 10^3\text{ J}}$$

Alternatively, we could start from

$$W = \int_{t_i}^{t_f} P dt = \int_0^{2\text{ s}} \left(48t + 288t^3\right)dt$$

**P8.48** The distance traveled by the ball from the top of the arc to the bottom is $\pi R$. The change in internal energy of the system due to the nonconservative force, the force exerted by the pitcher, is

$$\Delta E = Fd\cos 0° = F(\pi R)$$

We shall assign the gravitational energy of the ball-Earth system to be zero with the ball at the bottom of the arc.

Then

$$\Delta E_{\text{mech}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 + mgy_f - mgy_i$$

becomes

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + mgy_i + F(\pi R) = \frac{1}{2}mv_i^2 + mg2R + F(\pi R)$$

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + (2mg + \pi F)R$$

Solve for $R$, which is the length of her arms.

$$R = \frac{\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2}{2mg + \pi F} = m\frac{v_f^2 - v_i^2}{4mg + 2\pi F}$$

$$R = (0.180 \text{ kg})\frac{(25.0 \text{ m/s})^2 - 0}{4(0.180 \text{ kg})g + 2\pi(12.0 \text{ N})} = 1.36 \text{ m}$$

$\boxed{\text{We find that her arms would need to be 1.36 m long to perform this task. This is significantly longer than the human arm.}}$

**P8.49** (a) $(K + U_g)_A = (K + U_g)_B$

$$0 + mgy_A = \frac{1}{2}mv_B^2 + 0$$

$$v_B = \sqrt{2gy_A} = \sqrt{2(9.80 \text{ m/s}^2)6.30 \text{ m}} = \boxed{11.1 \text{ m/s}}$$

(b) $(K + U_g + U_{\text{chemical}})_B = (K + U_g)_D$

$$\frac{1}{2}mv_B^2 + U_{\text{chemical}} = \frac{1}{2}mv_D^2 + mg(y_D - y_B)$$

$$U_{\text{chemical}} = \frac{1}{2}mv_D^2 - \frac{1}{2}mv_B^2 + mg(y_D - y_B)$$

$$= \frac{1}{2}m(v_D^2 - v_B^2) + mg(y_D - y_B)$$

$$U_{\text{chemical}} = \frac{1}{2}(76.0 \text{ kg})\left[(5.14 \text{ m/s})^2 - (11.1 \text{ m/s})^2\right] + (76.0 \text{ kg})(9.80 \text{ m/s}^2)(6.30 \text{ m})$$

$$U_{\text{chemical}} = \boxed{1.00 \times 10^3 \text{ J}}$$

(c) $(K + U_g)_D = (K + U_g)_E$ where $E$ is the apex of his motion:

$$\frac{1}{2}mv_D^2 + 0 = 0 + mg(y_E - y_D)$$

$$y_E - y_D = \frac{v_D^2}{2g} = \frac{(5.14 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)} = \boxed{1.35 \text{ m}}$$

**P8.50** (a) Simplified, the equation is

$$0 = (9700 \text{ N/m})x^2 - (450.8 \text{ N})x - 1395 \text{ N} \cdot \text{m}$$

Then

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{450.8\ \text{N} \pm \sqrt{(450.8\ \text{N})^2 - 4(9700\ \text{N/m})(-1395\ \text{N}\cdot\text{m})}}{2(9700\ \text{N/m})}$$

$$= \frac{450.8\ \text{N} \pm 7370\ \text{N}}{19\ 400\ \text{N/m}} = \boxed{0.403\ \text{m or } -0.357\ \text{m}}$$

(b) From a perch at a height of 2.80 m above the top of a pile of mattresses, a 46.0-kg child jumps upward at 2.40 m/s. The mattresses behave as a linear spring with force constant 19.4 kN/m. Find the maximum amount by which they are compressed when the child lands on them.

(c) 0.023 2 m.

(d) This result is the distance by which the mattresses compress if the child just stands on them. It is the location of the equilibrium position of the oscillator.

**P8.51** (a) The total external work done on the system of Jonathan-bicycle is

$$W = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$= \frac{1}{2}(85.0\ \text{kg})\left[(1.00\ \text{m/s})^2 - (6.00\ \text{m/s})^2\right]$$

$$= \boxed{-1\ 490\ \text{J}}$$

(b) Gravity does work on the Jonathan-bicycle system, and the potential (chemical) energy stored in Jonathan's body is transformed into kinetic energy:

$$\Delta K + \Delta U_{\text{chem}} = W_g$$

$$\Delta U_{\text{chem}} = W_g - \Delta K = -mgh - \Delta K$$

$$\Delta U_{\text{chem}} = -(85.0\ \text{kg})g(7.30\ \text{m}) - \Delta K = -6\ 080 - 1\ 490$$

$$= \boxed{-7\ 570\ \text{J}}$$

(c) Jonathan does work on the bicycle (and his mass). Treat his work as coming from outside the bicycle-Jonathan's mass system:

$$\Delta K + \Delta U_g = W_j$$

$$W_f = \Delta K + mgh = -1\ 490\ \text{J} + 6\ 080\ \text{J} = \boxed{4\ 590\ \text{J}}$$

**P8.52** (a) The total external work done on the system of Jonathan-bicycle is

$$W = \Delta K = \boxed{\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2}$$

(b) Gravity does work on the Jonathan-bicycle system, and the potential (chemical) energy stored in Jonathan's body is transformed into kinetic energy:

$$\Delta K + \Delta U_{\text{chem}} = W_g$$

$$\Delta U_{\text{chem}} = W_g - \Delta K = \boxed{-mgh - \left(\frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2}\right)}$$

(c) Jonathan does work on the bicycle (and his mass). Treat his work as coming from outside the bicycle-Jonathan's mass system:

$$\Delta K + \Delta U_g = W_j$$

$$W_j = \Delta K + mgh = \boxed{\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 + mgh}$$

**P8.53** (a) The block-spring-surface system is isolated with a nonconservative force acting. Therefore, Equation 8.2 becomes

$$\Delta K + \Delta U + \Delta E_{\text{int}} = 0$$

$$\left(\tfrac{1}{2}mv^2 - 0\right) + \left(\tfrac{1}{2}kx^2 - \tfrac{1}{2}kx_i^{\ 2}\right) + f_k\left(x_i - x\right) = 0$$

To find the maximum speed, differentiate the equation with respect to $x$:

$$mv\frac{dv}{dx} + kx - f_k = 0$$

Now set $dv/dx = 0$:

$$kx - f_k = 0 \rightarrow \quad x = \frac{f_k}{k} = \frac{4.0\ \text{N}}{1.0 \times 10^3\ \text{N/m}} = 4.0 \times 10^{-3}\ \text{m}$$

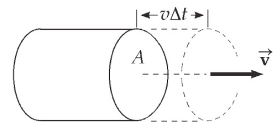
This is the compression distance of the spring, so the position of the block relative to $x = 0$ is $\boxed{x = -4.0 \times 10^{-3}\ \text{m.}}$

(b) By the same approach,

$$kx - f_k = 0 \rightarrow \quad x = \frac{f_k}{k} = \frac{10.0 \text{ N}}{1.0 \times 10^3 \text{ N/m}} = 1.0 \times 10^{-2} \text{ m}$$

so the position of the block is $\boxed{x = -1.0 \times 10^{-2} \text{ m.}}$

**P8.54** $P\Delta t = W = \Delta K = \dfrac{(\Delta m)v^2}{2}$




ANS. FIG. P8.54

The density is $\rho = \dfrac{\Delta m}{\text{volume}} = \dfrac{\Delta m}{A\Delta x}$

Substituting this into the first equation and solving for $P$, since $\dfrac{\Delta x}{\Delta t} = v$ for a constant speed, we get

$$P = \boxed{\frac{\rho A v^3}{2}}$$

Also, since $P = Fv$,

$$\boxed{F = \frac{\rho A v^2}{2}}$$

Our model predicts the same proportionalities as the empirical equation, and gives $D = 1$ for the drag coefficient. Air actually slips around the moving object, instead of accumulating in front of it. For this reason, the drag coefficient is not necessarily unity. It is typically less than one for a streamlined object and can be greater than one if the airflow around the object is complicated.

**P8.55** $P = \dfrac{1}{2} D\rho\pi r^2 v^3$

(a) We use 1.20 kg/m³ for the density of air, and calculate

$$P_a = \frac{1}{2}(1)\left(1.20 \text{ kg/m}^3\right)\pi(1.50 \text{ m})^2(8.00 \text{ m/s})^3$$
$$= \boxed{2.17 \times 10^3 \text{ W}}$$

(b) We solve part (b) by proportion:

$$\frac{P_b}{P_a} = \frac{v_b^3}{v_a^3} = \left(\frac{24 \text{ m/s}}{8 \text{ m/s}}\right)^3 = 3^3 = 27$$

$$P_b = 27\left(2.17 \times 10^3 \text{ W}\right) = 5.86 \times 10^4 \text{ W} = \boxed{58.6 \text{ kW}}$$

**P8.56** (a) In Example 8.3, $m = 35.0\ g$, $y_A = -0.120$ m, $y_B = 0$, and $k = 958$ N/m. Friction $f_k = 2.00$ N acts over distance $d = 0.600$ m. For the ball-spring-Earth system, $K_i = 0$, $U_{gi} = mgy_A$, $U_{si} = \frac{1}{2}kx^2$, where $x = |y_A|$; $K_f = 0$, $U_{gf} = mgy_C$, and $U_{sf} = 0$.

$$\Delta K + \Delta U = -f_k d$$

$$0 + (mgy_C - mgy_A) + \left(0 - \frac{1}{2}kx^2\right) = -f_k d$$

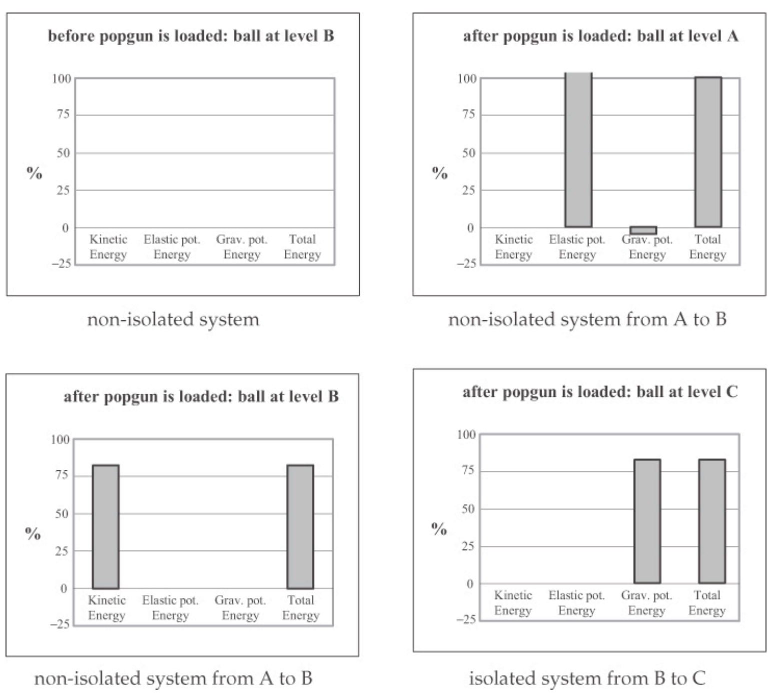
$$mgy_C = mgy_A + \frac{1}{2}kx^2 - f_k d$$

$$y_C = y_A + \frac{\frac{1}{2}kx^2 - f_k d}{mg}$$

$$= -0.120 + \frac{\frac{1}{2}(958\ \text{N/m})(0.120\ \text{m})^2 - (2.00\ \text{N})(0.600\ \text{m})}{(0.035\ \text{kg})g}$$

$$= \boxed{16.5\ \text{m}}$$

(b) The ball-spring-Earth system is not isolated as the popgun is loaded. In addition, as the ball travels up the barrel, a nonconservative force acts within the system. The system is isolated after the ball leaves the barrel.




**ANS. FIG. P8.56**

**P8.57** (a) To calculate the change in kinetic energy, we integrate the expression for $a$ as a function of time to obtain the car's velocity:

$$v = \int_0^t a\,dt = \int_0^t \left(1.16t - 0.210t^2 + 0.240t^3\right)dt$$

$$= 1.16\frac{t^2}{2} - 0.210\frac{t^3}{3} + 0.240\frac{t^4}{4}\Bigg|_0^t = 0.580t^2 - 0.070t^3 + 0.060t^4$$

At $t = 0$, $v_i = 0$. At $t = 2.5$ s,

$$v_f = \left(0.580 \text{ m/s}^3\right)(2.50 \text{ s})^2 - \left(0.070 \text{ m/s}^4\right)(2.50 \text{ s})^3 + \left(0.060 \text{ m/s}^5\right)(2.50 \text{ s})^4 = 4.88 \text{ m/s}$$

The change in kinetic energy during this interval is then

$$K_i + W = K_f$$

$$0 + W = \frac{1}{2}mv_f^2 = \frac{1}{2}(1\,160 \text{ kg})(4.88 \text{ m/s})^2 = \boxed{1.38\times10^4 \text{ J}}$$

(b) The road does work on the car when the engine turns the wheels and the car moves. The engine and the road together transform chemical potential energy in the gasoline into kinetic energy of the car.

$$P = \frac{W}{\Delta t} = \frac{1.38\times10^4 \text{ J}}{2.50 \text{ s}}$$

$$P = \boxed{5.52\times10^3 \text{ W}}$$

(c) The value in (b) represents only energy that leaves the engine and is transformed to kinetic energy of the car. Additional energy leaves the engine by sound and heat. More energy leaves the engine to do work against friction forces and air resistance.

**P8.58** At the bottom of the circle, the initial speed of the coaster is 22.0 m/s. As the coaster travels up the circle, it will slow down. At the top of the track, the centripetal acceleration must be at least that of gravity, $g$, to remain on the track. Apply conservation of energy to the roller coaster-Earth system to find the speed of the coaster at the top of the circle so that we may find the centripetal acceleration of the coaster.

$$\Delta K + \Delta U = 0$$

$$\left(\frac{1}{2}mv_{\text{top}}^2 - \frac{1}{2}mv_{\text{bottom}}^2\right) + \left(mgy_{\text{top}} - mgy_{\text{bottom}}\right) = 0$$

$$\left(\frac{1}{2}mv_{\text{top}}^2 - \frac{1}{2}mv_{\text{bottom}}^2\right) + \left(mg2R - 0\right) = 0 \rightarrow v_{\text{top}}^2 = v_{\text{bottom}}^2 - 4gR$$

$$v_{\text{top}}^2 = (22.0\text{ m/s})^2 - 4g(12.0\text{ m}) = 13.6\text{ m}^2/\text{s}^2$$

For this speed, the centripetal acceleration is

$$a_c = \frac{v_{\text{top}}^2}{R} = \frac{13.6\text{ m}^2/\text{s}^2}{12.0\text{ m}} = 1.13\text{ m/s}^2$$

The centripetal acceleration of each passenger as the coaster passes over the top of the circle is $1.13\text{ m/s}^2$. Since this is less than the acceleration due to gravity, the unrestrained passengers will fall out of the cars!

**P8.59** (a) The energy stored in the spring is the elastic potential energy, $U = \frac{1}{2}kx^2$, where $k = 850\text{ N/m}$. At $x = 6.00\text{ cm}$,

$$U = \frac{1}{2}kx^2 = \frac{1}{2}(850\text{ N/m})(0.0600\text{ m})^2 = \boxed{1.53\text{ J}}$$

At the equilibrium position, $x = 0$, $U = \boxed{0\text{ J}}$.

(b) Applying energy conservation to the block-spring system:

$$\Delta K + \Delta U = 0$$

$$\left(\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2\right) + \left(U_f - U_i\right) = 0 \rightarrow \left(\frac{1}{2}mv_f^2 - 0\right) = -\left(U_f - U_i\right)$$

$$\frac{1}{2}mv_f^2 = U_i - U_f$$

because the block is released from rest. For $x_f = 0$, $U = 0$, and

$$\frac{1}{2}mv_f^2 = U_i - U_f \rightarrow v_f = \sqrt{\frac{2\left(U_i - U_f\right)}{m}}$$

$$v_f = \sqrt{\frac{2(1.53\text{ J})}{1.00\text{ kg}}}$$

$$\boxed{v_f = 1.75\text{ m/s}}$$

(c) From (b) above, for $x_f = x_i/2 = 3.00\text{ cm}$,

$$U = \frac{1}{2}kx^2 = \frac{1}{2}(850\text{ N/m})(0.0300\text{ m})^2 = 0.383\text{ J}$$

and

$$\frac{1}{2}mv_f^2 = U_i - U_f \rightarrow v_f = \sqrt{\frac{2(U_i - U_f)}{m}}$$

$$v_f = \sqrt{\frac{2(1.53\text{ J} - 0.383\text{ J})}{1.00\text{ kg}}} = \sqrt{\frac{2(1.15\text{ J})}{1.00\text{ kg}}}$$

$$\boxed{v_f = 1.51\text{ m/s}}$$

**P8.60** (a) The suggested equation $P\Delta t = bwd$ implies all of the following cases:

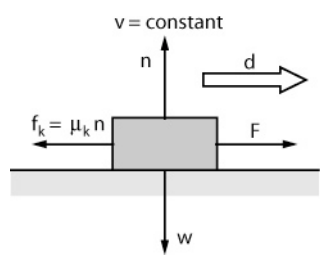
(1) $P\Delta t = b\left(\frac{w}{2}\right)(2d)$

(2) $P\left(\frac{\Delta t}{2}\right) = b\left(\frac{w}{2}\right)d$

(3) $P\left(\frac{\Delta t}{2}\right) = bw\left(\frac{d}{2}\right)$ and

(4) $\left(\frac{P}{2}\right)\Delta t = b\left(\frac{w}{2}\right)d$

These are all of the proportionalities Aristotle lists.




**ANS FIG. P8.60**

(b) For one example, consider a horizontal force $F$ pushing an object of weight $w$ at constant velocity across a horizontal floor with which the object has coefficient of friction $\mu_k$.

$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ implies that

$$+n - w = 0 \text{ and } F - \mu_k n = 0$$

so that $F = \mu_k w$.

As the object moves a distance $d$, the agent exerting the force does work

$$W = Fd\cos\theta = Fd\cos 0° = \mu_k wd$$

and puts out power $P = \dfrac{W}{\Delta t}$

This yields the equation $P\Delta t = \mu_k wd$ which represents Aristotle's theory with $b = \mu_k$.

Our theory is more general than Aristotle's. Ours can also describe accelerated motion.

**P8.61** $k = 2.50 \times 10^4$ N/m, $m = 25.0$ kg

$x_A = -0.100$ m, $U_g\big|_{x=0} = U_s\big|_{x=0} = 0$

(a) At point A, the total energy of the child-pogo-stick-Earth system is given by

$$E_{\text{mech}} = K_A + U_{gA} + U_s \quad \rightarrow \quad E_{\text{mech}} = 0 + mgx_A + \frac{1}{2}kx_A^2$$

$$E_{\text{mech}} = (25.0\text{ kg})(9.80\text{ m/s}^2)(-0.100\text{ m}) + \frac{1}{2}(2.50\times 10^4\text{ N/m})(-0.100\text{ m})^2$$

$$E_{\text{mech}} = -24.5\text{ J} + 125\text{ J} = \boxed{100\text{ J}}$$

(b) Since only conservative forces are involved, the total energy of the child-pogo-stick-Earth system at point *C* is the same as that at point *A*.

$$K_C + U_{gC} + U_{sC} = K_A + U_{gA} + U_{sA}$$

$$0 + (25.0\text{ kg})(9.80\text{ m/s}^2)x_C + 0 = 0 - 24.5\text{ J} + 125\text{ J}$$

$$x_C = \boxed{0.410\text{ m}}$$

(c) $K_B + U_{gB} + U_{sB} = K_A + U_{gA} + U_{sA}$

$$\frac{1}{2}(25.0\text{ kg})v_B^2 + 0 + 0 = 0 + (-24.5\text{ J}) + 125\text{ J}$$

$$v_B = \boxed{2.84\text{ m/s}}$$

(d) The energy of the system for configurations in which the spring is compressed is

$$E = K + \frac{1}{2}kx^2 - mgx$$

where $x$ is the compression distance of the spring.

To find the position $x$ for which the kinetic energy is a maximum, solve this expression for $K$, differentiate with respect to $x$, and set the result equal to zero:

$$K = E - \frac{1}{2}kx^2 + mgx$$

$$\frac{dK}{dx} = 0 - kx + mg = 0 \quad \rightarrow \quad x = \frac{mg}{k}$$

Substitute numerical values:

$$x = \frac{(25.0 \text{ kg})(9.80 \text{ m/s}^2)}{2.50 \times 10^4 \text{ N/m}} = 0.009\ 8 \text{ m} = 0.98 \text{ cm}$$

Because this is the value for the compression distance of the spring, this position is 0.98 cm below $x = 0$.

$$K = K_{\max} \text{ at } x = \boxed{-9.80 \text{ mm}}$$

(e) $K_{\max} = K_A + \left(U_{gA} - U_g\big|_{x=-9.80\text{ mm}}\right) + \left(U_{sA} - U_s\big|_{x=-9.80\text{ mm}}\right)$

or

$$\frac{1}{2}(25.0 \text{ kg})v_{\max}^2$$

$$= (25.0 \text{ kg})(9.80 \text{ m/s}^2)\left[(-0.100 \text{ m}) - (-0.009\ 8 \text{ m})\right]$$

$$+\frac{1}{2}(2.50 \times 10^4 \text{ N/m})\left[(-0.100 \text{ m})^2 - (-0.009\ 8 \text{ m})^2\right]$$

yielding $v_{\max} = \boxed{2.85 \text{ m/s}}$

**P8.62** (a) Between the second and the third picture, $\Delta E_{\text{mech}} = \Delta K + \Delta U$:

$$-\mu mgd = -\frac{1}{2}mv_i^2 + \frac{1}{2}kd^2$$

$$\frac{1}{2}(50.0 \text{ N/m})d^2 + 0.250(1.00 \text{ kg})(9.80 \text{ m/s}^2)d$$

$$-\frac{1}{2}(1.00 \text{ kg})(3.00 \text{ m/s})^2 = 0$$

$$d = \frac{[-2.45 \pm 21.35] \text{ N}}{50.0 \text{ N/m}} = \boxed{0.378 \text{ m}}$$

(b) Between picture two and picture four, $\Delta E_{\text{mech}} = \Delta K + \Delta U$:

$$-\mu mg(2d) = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

which gives

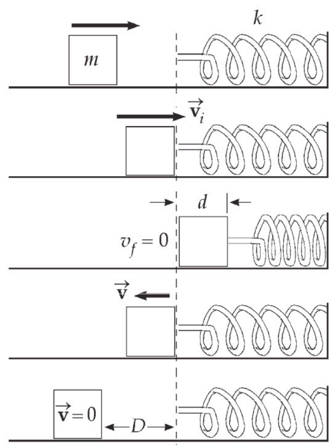
$$v_f = \sqrt{(3.00\ \text{m/s})^2 - \frac{2}{(1.00\ \text{kg})}(2.45\ \text{N})(2)(0.378\ \text{m})}$$

$$= \boxed{2.30\ \text{m/s}}$$

(c) For the motion from picture two to picture five in the figure below, $\Delta E_{\text{mech}} = \Delta K + \Delta U$:

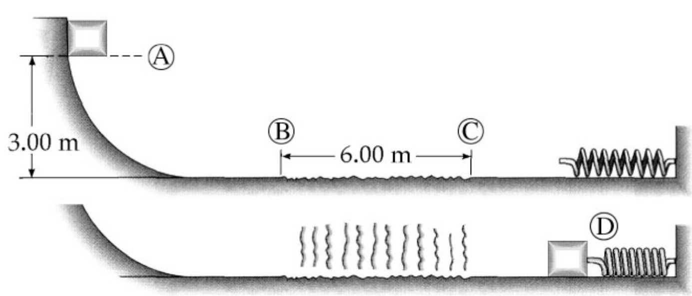
$$-\mu mg(D + 2d) = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$D = \frac{(1.00\ \text{kg})(3.00\ \text{m/s})^2}{2(0.250)(1.00\ \text{kg})(9.80\ \text{m/s}^2)} - 2(0.378\ \text{m}) = \boxed{1.08\ \text{m}}$$




**ANS. FIG P8.62**

**P8.63** The easiest way to solve this problem about a chain-reaction process is by considering the energy changes experienced by the block between the point of release (initial) and the point of full compression of the spring (final). Recall that the change in potential energy (gravitational and elastic) plus the change in kinetic energy must equal the work done on the block by non-conservative forces. We choose the gravitational potential energy to be zero along the flat portion of the track.




**ANS. FIG. P8.63**

There is zero spring potential energy in situation Ⓐ and zero gravitational potential energy in situation Ⓓ. Putting the energy equation into symbols:

$$K_D - K_A - U_{gA} + U_{sD} = -f_k d_{BC}$$

Expanding into specific variables:

$$0 - 0 - mgy_A + \frac{1}{2}kx_s^2 = -f_k d_{BC}$$

The friction force is $f_k = \mu_k mg$, so

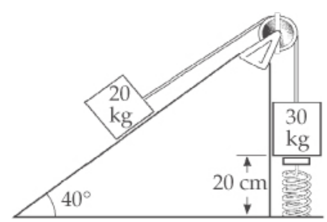
$$mgy_A - \frac{1}{2}kx^2 = \mu_k mgd$$

Solving for the unknown variable $\mu_k$ gives

$$\mu_k = \frac{y_A}{d} - \frac{kx^2}{2mgd}$$

$$= \frac{3.00\text{ m}}{6.00\text{ m}} - \frac{(2\,250\text{ N/m})(0.300\text{ m})^2}{2(10.0\text{ kg})(9.80\text{ m/s}^2)(6.00\text{ m})} = \boxed{0.328}$$

**P8.64** We choose the zero configuration of potential energy for the 30.0-kg block to be at the unstretched position of the spring, and for the 20.0-kg block to be at its lowest point on the incline, just before the system is released from rest. From conservation of energy, we have




**ANS. FIG. P8.64**

$$(K + U)_i = (K + U)_f$$

$$0 + (30.0\text{ kg})(9.80\text{ m/s}^2)(0.200\text{ m}) + \frac{1}{2}(250\text{ N/m})(0.200\text{ m})^2$$

$$= \frac{1}{2}(20.0\text{ kg} + 30.0\text{ kg})v^2$$

$$+ (20.0\text{ kg})(9.80\text{ m/s}^2)(0.200\text{ m})\sin 40.0°$$

$$58.8\text{ J} + 5.00\text{ J} = (25.0\text{ kg})v^2 + 25.2\text{ J}$$

$$\boxed{v = 1.24\text{ m/s}}$$

**P8.65** (a) For the isolated spring-block system,

$$\Delta K + \Delta U = 0$$

$$\left(\frac{1}{2}mv^2 - 0\right) + \left(0 - \frac{1}{2}kx^2\right) = 0$$

$$x = \sqrt{\frac{m}{k}}v = \sqrt{\frac{0.500\text{ kg}}{450\text{ N/m}}}\,(12.0\text{ m/s})$$

$$x = \boxed{0.400\text{ m}}$$

(b) $\Delta K + \Delta U + \Delta E_{\text{int}} = 0$

$$\left(\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2\right) + (2mgR - 0) + f_k(\pi R) = 0$$

$$v_f = \sqrt{v_i^2 - 4gR - \frac{2\pi f_k R}{m}}$$

$$= \sqrt{(12.0\text{ m/s})^2 - 4(9.80\text{ m/s}^2)(1.00\text{ m}) - \frac{2\pi(7.00\text{ N})(1.00\text{ m})}{0.500\text{ kg}}}$$

$$v_f = \boxed{4.10\text{ m/s}}$$

(c) Does the block fall off at or before the top of the track? The block falls if $a_c < g$.

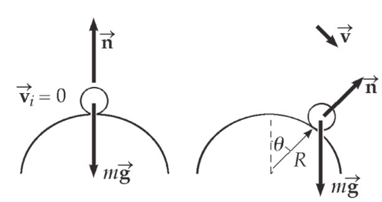
$$a_c = \frac{v_T^2}{R} = \frac{(4.10\text{ m/s})^2}{1.00\text{ m}} = 16.8\text{ m/s}^2$$

Therefore $a_c > g$ and the $\boxed{\text{block stays on the track}}$.

**P8.66** $m$ = mass of pumpkin

$R$ = radius of silo top

$$\sum F_r = ma_r \Rightarrow n - mg\cos\theta = -m\frac{v^2}{R}$$




**ANS. FIG. P8.66**

When the pumpkin first loses contact with the surface, $n = 0$.

Thus, at the point where it leaves the surface: $v^2 = Rg\cos\theta$.

Choose $U_g = 0$ in the $\theta = 90.0°$ plane. Then applying conservation of energy for the pumpkin-Earth system between the starting point and the point where the pumpkin leaves the surface gives

$$K_f + U_{gf} = K_i + U_{gi}$$

$$\frac{1}{2}mv^2 + mgR\cos\theta = 0 + mgR$$

Using the result from the force analysis, this becomes

$$\frac{1}{2}mRg\cos\theta + mgR\cos\theta = mgR\text{, which reduces to}$$

$$\cos\theta = \frac{2}{3}\text{, and gives } \theta = \cos^{-1}(2/3) = \boxed{48.2°}$$

as the angle at which the pumpkin will lose contact with the surface.

**P8.67** Convert the speed to metric units:

$$v = (100\ \text{km/h})\left(\frac{1\ 000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3\ 600\ \text{s}}\right) = 27.8\ \text{m/s}$$

Write Equation 8.2 for this situation, treating the car and surrounding air as an isolated system with a nonconservative force acting:

$$\Delta K + \Delta U_{\text{grav}} + \Delta U_{\text{fuel}} + \Delta E_{\text{int}} = 0$$

The power of the engine is a measure of how fast it can convert chemical potential energy in the fuel to other forms. The magnitude of the change in energy to other forms is equal to the negative of the change in potential energy in the fuel: $\Delta E_{\text{other forms}} = -\Delta U_{\text{fuel}}$. Therefore, if the car moves a distance $d$ along the hill,

$$P = -\frac{\Delta U_{\text{fuel}}}{\Delta t} = -\frac{\left(-\Delta K - \Delta U_{\text{grav}} - \Delta E_{\text{int}}\right)}{\Delta t}$$

$$= \frac{0 + \left(mgd\sin 3.2° - 0\right) + \frac{1}{2}D\rho Av^2 d}{\Delta t}$$

$$= mgv\sin 3.2° + \frac{1}{2}D\rho Av^3$$

where we have recognized $d/\Delta t$ as the speed $v$ of the car. Substituting numerical values,

$$P = (1\ 500\ \text{kg})(9.80\ \text{m/s}^2)(27.8\ \text{m/s})\sin 3.2° + \frac{1}{2}(0.330)(1.20\ \text{kg/m}^3)(2.50\ \text{m}^2)(27.8\ \text{m/s})^3$$

$$\boxed{P = 33.4\ \text{kW} = 44.8\ \text{hp}}$$

The actual power will be larger than this because additional energy coming from the engine is used to do work against internal friction in the moving parts of the car and rolling friction with the road. In addition, some energy from the engine is radiated away by sound. Finally, some of the energy from the fuel raises the internal energy of the engine, and energy leaves the warm engine by heat into the cooler air.

**P8.68** (a) Energy is conserved in the swing of the pendulum, and the stationary peg does no work. So the ball's speed does not change when the string hits or leaves the peg, and the ball swings equally high on both sides.

(b) The ball will swing in a circle of radius $R = (L - d)$ about the peg. If the ball is to travel in the circle, the minimum centripetal acceleration at the top of the circle must be that of gravity:

$$\frac{mv^2}{R} = g \;\rightarrow\; v^2 = g(L-d)$$

When the ball is released from rest, $U_i = mgL$, and when it is at the top of the circle, $U_i = mg2(L - d)$, where height is measured from the bottom of the swing. By energy conservation,

$$mgL = mg2(L-d) + \frac{1}{2}mv^2$$

From this and the condition on $v^2$ we find $\boxed{d = \frac{3L}{5}}$.

**P8.69** If the spring is just barely able to lift the lower block from the table, the spring lifts it through no noticeable distance, but exerts on the block a force equal to its weight $Mg$. The extension of the spring, from $\left|\vec{\mathbf{F}}_s\right| = kx$, must be $Mg/k$. Between an initial point at release and a final point when the moving block first comes to rest, we have

$$K_i + U_{gi} + U_{si} = K_f + U_{gf} + U_{sf}$$

$$0 + mg\left(-\frac{4mg}{k}\right) + \frac{1}{2}k\left(\frac{4mg}{k}\right)^2 = 0 + mg\left(\frac{Mg}{k}\right) + \frac{1}{2}k\left(\frac{Mg}{k}\right)^2$$

$$-\frac{4m^2g^2}{k} + \frac{8m^2g^2}{k} = \frac{mMg^2}{k} + \frac{M^2g^2}{2k}$$

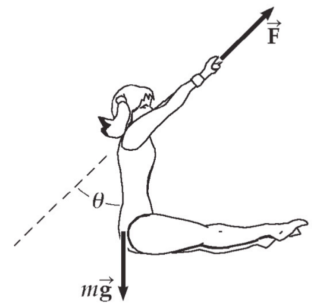
$$4m^2 = mM + \frac{M^2}{2}$$

$$\frac{M^2}{2} + mM - 4m^2 = 0$$

$$M = \frac{-m \pm \sqrt{m^2 - 4\left(\frac{1}{2}\right)\left(-4m^2\right)}}{2\left(\frac{1}{2}\right)} = -m \pm \sqrt{9m^2}$$

Only a positive mass is physical, so we take $M = m(3-1) = \boxed{2m}$.

**P8.70** The force needed to hang on is equal to the force $F$ the trapeze bar exerts on the performer. From the free-body diagram for the performer's body, as shown,




**ANS. FIG. P8.70**

$$F - mg\cos\theta = m\frac{v^2}{\ell}$$

or
$$F = mg\cos\theta + m\frac{v^2}{\ell}$$

At the bottom of the swing, $\theta = 0°$, so

$$F = mg + m\frac{v^2}{\ell}$$

The performer cannot sustain a tension of more than $1.80mg$. What is the force $F$ at the bottom of the swing? To find out, apply conservation of mechanical energy of the performer-Earth system as the performer moves between the starting point and the bottom:

$$mg\ell(1 - \cos 60.0°) = \frac{1}{2}mv^2 \rightarrow \frac{mv^2}{\ell} = 2mg(1 - \cos 60.0°) = mg$$

Hence, $F = mg + m\dfrac{v^2}{\ell} = mg + mg = 2mg$ at the bottom.

| The tension at the bottom is greater than the performer can withstand; therefore the situation is impossible. |
|---|

***P8.71** We first determine the energy output of the runner:

$$= (0.600 \text{ J/kg} \cdot \text{step})(60.0 \text{ kg})\left(\frac{1 \text{ step}}{1.50 \text{ m}}\right) = 24.0 \text{ J/m}$$

From this we calculate the force exerted by the runner per step:

$$F = (24.0 \text{ J/m})(1 \text{ N} \cdot \text{m/J}) = 24.0 \text{ N}$$

Then, from the definition of power, $P = Fv$, we obtain

$$v = \frac{P}{F} = \frac{70.0 \text{ W}}{24.0 \text{ N}} = \boxed{2.92 \text{ m/s}}$$

**P8.72** (a) At the top of the loop the car and riders are in free fall:

$$\sum F_y = ma_y:$$

$$mg \text{ down} = \frac{mv^2}{R} \text{ down}$$

$$v = \sqrt{Rg}$$

Energy of the car-riders-Earth system is conserved between release and top of loop:

$$K_i + U_{gi} = K_f + U_{gf}:$$

$$0 + mgh = \frac{1}{2}mv^2 + mg(2R)$$

$$gh = \frac{1}{2}Rg + g(2R)$$

$$\boxed{h = \frac{5R}{2}}$$

(b) Let $h$ now represent the height $\geq 2.5\,R$ of the release point. At the bottom of the loop we have

$$mgh = \frac{1}{2}mv_b^2$$

or $v_b^2 = 2gh$

then, from $\sum F_y = ma_y$:

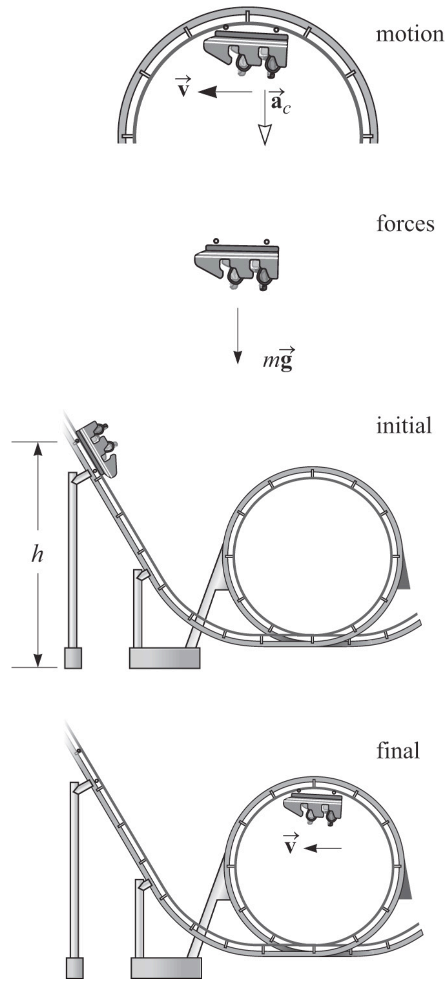
$$n_b - mg = \frac{mv_b^2}{R}(\text{up})$$

$$n_b = mg + \frac{m(2gh)}{R}$$

At the top of the loop,

$$mgh = \frac{1}{2}mv_t^2 + mg(2R)$$

$$v_t^2 = 2gh - 4gR$$




**ANS. FIG. P8.72**

from $\sum F_y = ma_y$:

$$-n_t - mg = -\frac{mv_t^2}{R}$$

$$n_t = -mg + \frac{m}{R}(2gh - 4gR)$$

$$n_t = \frac{m(2gh)}{R} - 5mg$$

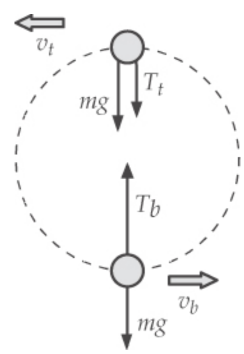
Then the normal force at the bottom is larger by

$$n_b - n_t = mg + \frac{m(2gh)}{R} - \frac{m(2gh)}{R} + 5mg = \boxed{6mg}$$

Note that this is the same result we will obtain for the difference in the tension in the string at the top and bottom of a vertical circle in Problem 73.

**P8.73** Applying Newton's second law at the bottom (*b*) and top (*t*) of the circle gives

$$T_b - mg = \frac{mv_b^2}{R} \quad \text{and} \quad -T_t - mg = -\frac{mv_t^2}{R}$$




**ANS. FIG. P8.73**

Adding these gives

$$T_b = T_t + 2mg + \frac{m(v_b^2 - v_t^2)}{R}$$

Also, energy must be conserved and $\Delta U + \Delta K = 0$.

So, $\dfrac{m(v_b^2 - v_t^2)}{2} + (0 - 2mgR) = 0$ and $\dfrac{m(v_b^2 - v_t^2)}{R} = 4mg$

Substituting into the above equation gives $\boxed{T_b = T_t + 6mg}$.

**P8.74** (a) $\boxed{\text{No.}}$ The system of the airplane and the surrounding air is nonisolated. There are two forces acting on the plane that move through displacements, the thrust due to the engine (acting across the boundary of the system) and a resistive force due to the air (acting within the system). Since the air resistance force is nonconservative, some of the energy in the system is transformed to internal energy in the air and the surface of the airplane. Therefore, the change in kinetic energy of the plane is less than the positive work done by the engine thrust. So, $\boxed{\text{mechanical energy is not conserved in this case.}}$

(b) Since the plane is in level flight, $U_{gf} = U_{gi}$ and the conservation of energy for nonisolated systems reduces to

$$\sum W_{\text{other forces}} = W = \Delta K + \Delta U + \Delta E_{\text{int}}$$

or

$$W = W_{\text{thrust}} = K_f - K_i - fs$$

$$F(\cos 0°)s = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 - f(\cos 180°)s$$

This gives

$$v_f = \sqrt{v_i^2 + \frac{2(F-f)s}{m}}$$

$$= \sqrt{(60.0\text{ m/s})^2 + \frac{2\left[(7.50-4.00)\times 10^4\text{ N}\right](500\text{ m})}{1.50\times 10^4\text{ kg}}}$$

$$v_f = \boxed{77.0\text{ m/s}}$$

**P8.75** (a) As at the end of the process analyzed in Example 8.8, we begin with a 0.800-kg block at rest on the end of a spring with stiffness constant 50.0 N/m, compressed 0.092 4 m. The energy in the spring is $(1/2)(50\text{ N/m})(0.092\,4\text{ m})^2 = 0.214$ J. To push the block back to the unstressed spring position would require work against friction of magnitude 3.92 N (0.092 4 m) = 0.362 J.

Because 0.214 J is less than 0.362 J, the spring cannot push the object back to $x = 0$.

(b) The block approaches the spring with energy

$$\frac{1}{2}mv^2 = \frac{1}{2}(0.800\text{ kg})(1.20\text{ m/s})^2 = 0.576\text{ J}$$

It travels against friction by equal distances in compressing the spring and in being pushed back out, so half of the initial kinetic energy is transformed to internal energy in its motion to the right and the rest in its motion to the left. The spring must possess one-half of this energy at its maximum compression:

$$\frac{0.576\text{ J}}{2} = \frac{1}{2}(50.0\text{ N/m})x^2$$

so $x = 0.107$ m

For the compression process we have the conservation of energy equation

$$0.576 \text{ J} + \mu_k\, 7.84 \text{ N}\left(0.107 \text{ m}\right)\cos 180° = 0.288 \text{ J}$$

$$\text{so } \mu_k = 0.288 \text{ J}/0.841 \text{ J} = \boxed{0.342}$$

As a check, the decompression process is described by

$$0.288 \text{ J} + \mu_k\, 7.84 \text{ N}\left(0.107 \text{ m}\right)\cos 180° = 0$$

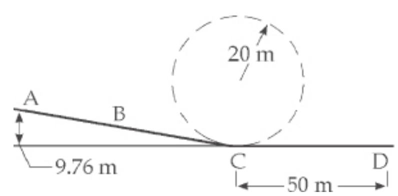
which gives the same answer for the coefficient of friction.

***P8.76** As it moves at constant speed, the bicycle is in equilibrium. The forward friction force is equal in magnitude to the air resistance, which we write as $av^2$, where $a$ is a proportionality constant. The exercising woman exerts the friction force on the ground; by Newton's third law, it is this same magnitude again. The woman's power output is $P = Fv = av^3 = ch$, where $c$ is another constant and $h$ is her heart rate. We are given $a(22 \text{ km/h})^3 = c(90 \text{ beats/min})$. For her minimum heart rate we have $av_{\text{min}}^3 = c(136 \text{ beats/min})$. By division $\left(\dfrac{v_{\text{min}}}{22 \text{ km/h}}\right)^3 = \dfrac{136}{90}$.

$$v_{\text{min}} = \left(\frac{136}{90}\right)^{1/3}(22 \text{ km/h}) = \boxed{25.2 \text{ km/h}}$$

$$\text{Similarly, } v_{\text{max}} = \left(\frac{166}{90}\right)^{1/3}(22 \text{ km/h}) = \boxed{27.0 \text{ km/h}}.$$

**P8.77** (a) Conservation of energy for the sled-rider-Earth system, between A and C:




**ANS. FIG. P8.77**

$$K_i + U_{gi} = K_f + U_{gf}$$

$$\frac{1}{2}m(2.50 \text{ m/s})^2 + m\left(9.80 \text{ m/s}^2\right)(9.76 \text{ m}) = \frac{1}{2}mv_C^2 + 0$$

$$v_C = \sqrt{(2.50 \text{ m/s})^2 + 2\left(9.80 \text{ m/s}^2\right)(9.76 \text{ m})} = \boxed{14.1 \text{ m/s}}$$

(b) Incorporating the loss of mechanical energy during the portion of the motion in the water, we have, for the entire motion between A and D (the rider's stopping point),

$$K_i + U_{gi} - f_k d = K_f + U_{gf}:$$

$$\frac{1}{2}(80.0\text{ kg})(2.50\text{ m/s})^2 + (80.0\text{ kg})(9.80\text{ m/s}^2)(9.76\text{ m}) - f_k d = 0 + 0$$

$$-f_k d = 7.90\times 10^3\text{ J}$$

The water exerts a friction force

$$f_k = \frac{7.90\times 10^3\text{ J}}{d} = \frac{7.90\times 10^3\text{ N}\cdot\text{m}}{50.0\text{ m}} = 158\text{ N}$$

and also a normal force of

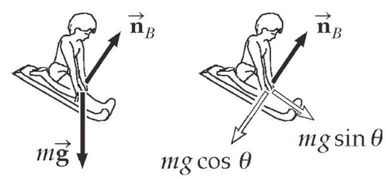
$$n = mg = (80.0\text{ kg})(9.80\text{ m/s}^2) = 784\text{ N}$$

The magnitude of the water force is

$$\sqrt{(158\text{ N})^2 + (784\text{ N})^2} = \boxed{800\text{ N}}$$

(c) The angle of the slide is

$$\theta = \sin^{-1}\left(\frac{9.76\text{ m}}{54.3\text{ m}}\right) = 10.4°$$




**ANS. FIG. P8.77(c)**

For forces perpendicular to the track at B,

$$\sum F_y = ma_y: \qquad n_B - mg\cos\theta = 0$$

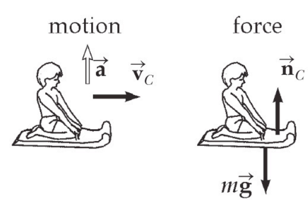
$$n_B = (80.0\text{ kg})(9.80\text{ m/s}^2)\cos 10.4° = \boxed{771\text{ N}}$$

(d) $\sum F_y = ma_y$:

$$+n_C - mg = \frac{mv_C^2}{r}$$

$$n_C = (80.0\text{ kg})(9.80\text{ m/s}^2) + \frac{(80.0\text{ kg})(14.1\text{ m/s})^2}{20.0\text{ m}}$$

$$n_C = \boxed{1.57\times 10^3\text{ N up}}$$




**ANS. FIG. P8.77(d)**

The rider pays for the thrills of a giddy height at A, and a high speed and tremendous splash at C. As a bonus, he gets the quick change in direction and magnitude among the forces we found in parts (d), (b), and (c).

**P8.78** (a) Maximum speed occurs after the needle leaves the spring, before it enters the body. We assume the needle is fired horizontally.


**ANS. FIG. P8.78(a)**

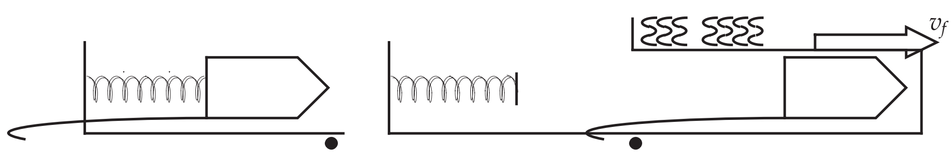
$$K_i + U_i - f_k d = K_f + U_f$$

$$0 + \frac{1}{2}kx^2 - 0 = \frac{1}{2}mv_{max}^2 + 0$$

$$\frac{1}{2}(375 \text{ N/m})(0.081 \text{ m})^2 = \frac{1}{2}(0.005\,6 \text{ kg})v_{max}^2$$

$$\left(\frac{2(1.23 \text{ J})}{0.005\,6 \text{ kg}}\right)^{1/2} = v_{max} = \boxed{21.0 \text{ m/s}}$$

(b) The same energy of 1.23 J as in part (a) now becomes partly internal energy in the soft tissue, partly internal energy in the organ, and partly kinetic energy of the needle just before it runs into the stop. We write a conservation of energy equation to describe this process:




**ANS. FIG. P8.78(b)**

$$K_i + U_i - f_{k1}d_1 - f_{k2}d_2 = K_f + U_f$$

$$0 + \frac{1}{2}kx^2 - f_{k1}d_1 - f_{k2}d_2 = \frac{1}{2}mv_f^2 + 0$$

$$1.23 \text{ J} - 7.60 \text{ N}(0.024 \text{ m}) - 9.20 \text{ N}(0.035 \text{ m}) = \frac{1}{2}(0.005\,6 \text{ kg})v_f^2$$

$$\left(\frac{2(1.23 \text{ J} - 0.182 \text{ J} - 0.322 \text{ J})}{0.005\,6 \text{ kg}}\right)^{1/2} = v_f = \boxed{16.1 \text{ m/s}}$$

## Challenge Problems

**P8.79** (a) Let $m$ be the mass of the whole board. The portion on the rough surface has mass $mx/L$. The normal force supporting it is $\dfrac{mxg}{L}$ and the friction force is $\dfrac{\mu_k mgx}{L} = ma$. Then

$$\boxed{a = \frac{\mu_k gx}{L} \text{ opposite to the motion}}$$

(b) In an incremental bit of forward motion $dx$, the kinetic energy converted into internal energy is $f_k dx = \dfrac{\mu_k mgx}{L} dx$. The whole energy converted is

$$\frac{1}{2}mv^2 = \int_0^L \frac{\mu_k mgx}{L} dx = \frac{\mu_k mg}{L} \frac{x^2}{2}\bigg|_0^L = \frac{\mu_k mgL}{2}$$

$$\boxed{v = \sqrt{\mu_k gL}}$$

**P8.80** (a) $U_g = mgy = (64.0 \text{ kg})(9.80 \text{ m/s}^2)y = \boxed{(627 \text{ N})y}$

(b) At the original height and at all heights above 65.0 m – 25.8 m = 39.2 m, the cord is unstretched and $\boxed{U_s = 0}$. Below 39.2 m, the cord extension $x$ is given by $x = 39.2 \text{ m} - y$, so the elastic energy is

$$U_s = \frac{1}{2}kx^2 = \boxed{\frac{1}{2}(81.0 \text{ N/m})(39.2 \text{ m} - y)^2}.$$

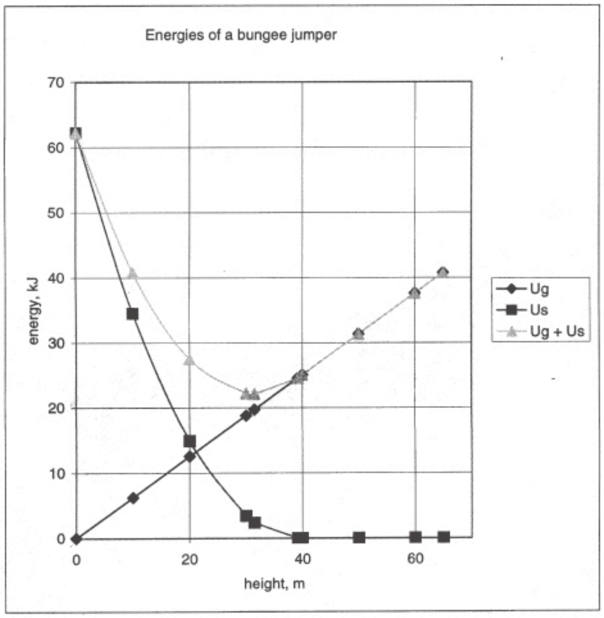
(c) For $y > 39.2$ m, $U_g + U_s = \boxed{(627 \text{ N})y}$

For $y \le 39.2$ m,

$$U_g + U_s = (627 \text{ N})y + 40.5 \text{ N/m}\left(1\,537 \text{ m}^2 - (78.4 \text{ m})y + y^2\right)$$

$$= \boxed{(40.5 \text{ N/m})y^2 - (2\,550 \text{ N})y + 62\,200 \text{ J}}$$

(d) See the graph in ANS. FIG. P8.80(d) below.




**ANS. FIG. P8.80(d)**

(e) At minimum height, the jumper has zero kinetic energy and the system has the same total energy as it had when the jumper was at his starting point. $K_i + U_i = K_f + U_f$ becomes

$$(627\ \text{N})(65.0\ \text{m}) = (40.5\ \text{N/m})y_f^2 - (2\ 550\ \text{N})y_f + 62\ 200\ \text{J}$$

Suppressing units,

$$0 = 40.5y_f^2 - 2\ 550y_f + 21\ 500$$

$$y_f = \boxed{10.0\ \text{m}}\ \left[\text{the solution 52.9 m is unphysical}\right]$$

(f) The total potential energy has a minimum, representing a $\boxed{\text{stable equilibrium}}$ position. To find it, we require $\dfrac{dU}{dy} = 0.$

Suppressing units, we get

$$\frac{d}{dy}\left(40.5y^2 - 2\ 550y + 62\ 200\right) = 0 = 81y - 2\ 550$$

$$y = \boxed{31.5\ \text{m}}$$

(g) Maximum kinetic energy occurs at minimum potential energy. Between the takeoff point and this location, we have

$$K_i + U_i = K_f + U_f$$

Suppressing units,

$$0 + 40\,800$$
$$= \frac{1}{2}(64.0)v_{\max}^2 + 40.5(31.5)^2 - 2\,550(31.5) + 62\,200$$
$$v_{\max} = \left(\frac{2(40\,800 - 22\,200)}{64.0 \text{ kg}}\right)^{1/2} = \boxed{24.1 \text{ m/s}}$$

**P8.81** The geometry reveals $D = L\sin\theta + L\sin\phi$,

$$50.0 \text{ m} = 40.0 \text{ m}(\sin 50° + \sin\phi),\ \phi = 28.9°$$

(a) From takeoff to landing for the Jane-Earth system:

$$\Delta K + \Delta U + \Delta E_{\text{int}} = 0$$
$$\left(0 - \frac{1}{2}mv_i^2\right) + \left[mg(-L\cos\phi) - mg(-L\cos\theta)\right] + FD = 0$$
$$\frac{1}{2}mv_i^2 + mg(-L\cos\theta) + FD(-1) = 0 + mg(-L\cos\phi)$$
$$\frac{1}{2}(50.0 \text{ kg})\,v_i^2 + (50.0 \text{ kg})(9.80 \text{ m/s}^2)(-40.0 \text{ m})\cos 50°$$
$$-(110 \text{ N})(50.0 \text{ m})$$
$$= (50.0 \text{ kg})(9.80 \text{ m/s}^2)(-40.0 \text{ m})\cos 28.9°$$
$$\frac{1}{2}(50.0 \text{ kg})v_i^2 - 1.26\times 10^4 \text{ J} - 5.5\times 10^3 \text{ J} = -1.72\times 10^4 \text{ J}$$
$$v_i = \sqrt{\frac{2(947 \text{ J})}{50.0 \text{ kg}}} = \boxed{6.15 \text{ m/s}}$$

(b) For the swing back:

$$\Delta K + \Delta U = \Delta E_{\text{mech}}$$
$$\left(0 - \frac{1}{2}mv_i^2\right) + \left[mg(-L\cos\theta) - mg(-L\cos\phi)\right] = FD$$
$$\frac{1}{2}mv_i^2 + mg(-L\cos\phi) + FD(+1) = 0 + mg(-L\cos\theta)$$
$$\frac{1}{2}(130 \text{ kg})v_i^2 + (130 \text{ kg})(9.80 \text{ m/s}^2)(-40.0 \text{ m})\cos 28.9°$$
$$+(110 \text{ N})(50.0 \text{ m})$$
$$= (130 \text{ kg})(9.80 \text{ m/s}^2)(-40.0 \text{ m})\cos 50°$$

$$\frac{1}{2}(130\text{ kg})v_i^2 - 4.46\times10^4\text{ J} + 5\,500\text{ J} = -3.28\times10^4\text{ J}$$

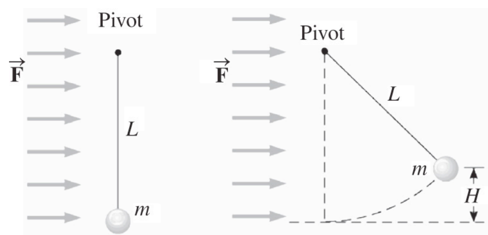
$$v_i = \sqrt{\frac{2(6\,340\text{ J})}{130\text{ kg}}} = \boxed{9.87\text{ m/s}}$$

**P8.82** (a) Take the original point where the ball is released and the final point where its upward swing stops at height $H$ and horizontal displacement

$$x = \sqrt{L^2 - (L-H)^2} = \sqrt{2LH - H^2}$$

Since the wind force is purely horizontal, it does work

$$W_{\text{wind}} = \int \vec{\mathbf{F}}\cdot d\vec{\mathbf{s}} = F\int dx = F\sqrt{2LH - H^2}$$




**ANS FIG. P8.82**

The work-energy theorem can be written:

$$K_i + U_{gi} + W_{\text{wind}} = K_f + U_{gf}\text{, or}$$

$$0 + 0 + F\sqrt{2LH - H^2} = 0 + mgH$$

giving

$$F^2 2LH - F^2H^2 = m^2g^2H^2$$

Here the solution $H = 0$ represents the lower turning point of the ball's oscillation, and the upper limit is at $F^2(2L) = (F^2 + m^2g^2)H$. Solving for $H$ yields

$$H = \frac{2LF^2}{F^2 + m^2g^2} = \frac{2L}{1 + (mg/F)^2}$$

$$= \frac{2(0.800\text{ m})}{1 + (0.300\text{ kg})^2(9.8\text{ m/s}^2)^2/F^2} = \boxed{\frac{1.60\text{ m}}{1 + 8.64\text{ N}^2/\text{F}^2}}$$

(b) $H = 1.6\text{ m}[1 + 8.64/1]^{-1} = \boxed{0.166\text{ m}}$

(c) $H = 1.6\text{ m}[1 + 8.64/100]^{-1} = \boxed{1.47\text{ m}}$

(d) As $F \to 0$, $\boxed{H \to 0\text{ as is reasonable.}}$

(e) As $F \to \infty$, $\boxed{H \to 1.60 \text{ m}}$, which would be hard to approach experimentally.

(f) Call $\theta$ the equilibrium angle with the vertical and $T$ the tension in the string.

$$\sum F_x = 0 \Rightarrow T\sin\theta = F, \text{ and}$$
$$\sum F_y = 0 \Rightarrow T\cos\theta = mg$$

Dividing: $\tan\theta = \dfrac{F}{mg}$

Then

$$\cos\theta = \frac{mg}{\sqrt{(mg)^2 + F^2}} = \frac{1}{\sqrt{1+(F/mg)^2}} = \frac{1}{\sqrt{1+F^2/8.64 \text{ N}^2}}$$

Therefore, $H_{\text{eq}} = L(1-\cos\theta) = \boxed{(0.800 \text{ m})\left(1 - \dfrac{1}{\sqrt{1+F^2/8.64 \text{ N}^2}}\right)}$

(g) For $F = 10$ N, $H_{eq} = 0.800 \text{ m}[1-(1+100/8.64)^{-1/2}] = \boxed{0.574 \text{ m}}$

(h) As $F \to \infty$, $\tan\theta \to \infty$, $\theta \to 90.0°$, $\cos\theta \to 0$, and $H_{eq} \to \boxed{0.800 \text{ m}}$.

A very strong wind pulls the string out horizontal, parallel to the ground.

**P8.83** The coaster-Earth system is isolated as the coaster travels up the circle. Find how high the coaster travels from the bottom:

$$K_i + U_i = K_f + U_f$$
$$\frac{1}{2}mv^2 + 0 = 0 + mgh \to h = \frac{v^2}{2g} = \frac{(15.0 \text{ m/s})^2}{2g} = 11.5 \text{ m}$$

For this situation, the coaster stops at height 11.5 m, which is lower than the height of 24 m at the top of the circular section; in fact, it is close to halfway to the top. The passengers will be supported by the normal force from the backs of their seats. Because of the usual position of a seatback, there may be a slight downhill incline of the seatback that would tend to cause the passengers to slide out. Between the force the passengers can exert by hanging on to a part of the car and the friction between their backs and the back of their seat, the passengers should be able to avoid sliding out of the cars. Therefore, this situation is $\boxed{\text{less dangerous}}$ than that in the original higher-speed situation, where the coaster is upside down.

**P8.84** (a) Let mass $m_1$ of the chain laying on the table and mass $m_2$ hanging off the edge. For the hanging part of the chain, apply the particle in equilibrium model in the vertical direction:

$$m_2 g - T = 0 \quad \textbf{[1]}$$

For the part of the chain on the table, apply the particle in equilibrium model in both directions:

$$n - m_1 g = 0 \quad \textbf{[2]}$$

$$T - f_s = 0 \quad \textbf{[3]}$$

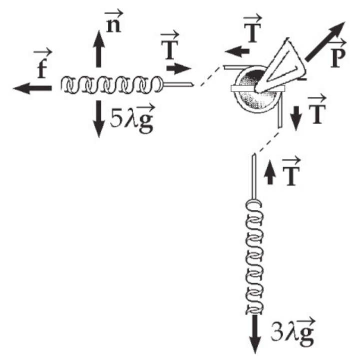
Assume that the length of chain hanging over the edge is such that the chain is on the verge of slipping. Add equations [1] and [3], impose the assumption of impending motion, and substitute equation [2]:

$$n - m_1 g = 0$$

$$f_s = m_2 g \quad \rightarrow \quad \mu_s n = m_2 g$$

$$\rightarrow \quad \mu_s m_1 g = m_2 g$$

$$\rightarrow \quad m_2 = \mu_s m_1 = 0.600 m_1$$




**ANS. FIG. P8.84**

From the total length of the chain of 8.00 m, we see that

$$m_1 + m_2 = 8.00\lambda$$

where $\lambda$ is the mass of a one meter length of chain. Substituting for $m_2$,

$$m_1 + 0.600 m_1 = 8.00\lambda \rightarrow 1.60 m_1 = 8.00\lambda \rightarrow m_1 = 5.00\lambda$$

From this result, we find that $\boxed{m_2 = 3.00\lambda}$ and we see that 3.00 m of chain hangs off the table in the case of impending motion.

(b) Let $x$ represent the variable distance the chain has slipped since the start.

Then length $(5 - x)$ remains on the table, with now

$$\sum F_y = 0: \qquad +n - (5 - x)\lambda g = 0 \quad \rightarrow \quad n = (5 - x)\lambda g$$

$$f_k = \mu_k n = 0.4(5 - x)\lambda g = 2\lambda g - 0.4 x \lambda g$$

Consider energies of the chain-Earth system at the initial moment when the chain starts to slip, and a final moment when $x = 5$, when the last link goes over the brink. Measure heights above the final position of the leading end of the chain. At the moment the final link slips off, the center of the chain is at $y_f = 4$ meters.

Originally, 5 meters of chain is at height 8 m and the middle of the dangling segment is at height $8-\frac{3}{2}=6.5$ m.

$$K_i+U_i+\Delta E_{\text{mech}}=K_f+U_f:$$

$$0+\left(m_1gy_1+m_2gy_2\right)_i-\int_i^f f_k dx=\left(\frac{1}{2}mv^2+mgy\right)_f$$

$$(5\lambda g)8+(3\lambda g)6.5-\int_0^5(2\lambda g-0.4x\lambda g)dx=\frac{1}{2}(8\lambda)v^2+(8\lambda g)4$$

$$40.0g+19.5g-2.00g\int_0^5 dx+0.400g\int_0^5 x\,dx=4.00v^2+32.0g$$

$$27.5g-2.00gx\Big|_0^5+0.400g\frac{x^2}{2}\Big|_0^5=4.00v^2$$

$$27.5g-2.00g(5.00)+0.400g(12.5)=4.00v^2$$

$$22.5g=4.00v^2$$

$$v=\sqrt{\frac{(22.5\text{ m})(9.80\text{ m/s}^2)}{4.00}}=\boxed{7.42\text{ m/s}}$$

**P8.85** (a) For a 5.00-m cord the spring constant is described by $F=kx$, $mg=k$ (1.50 m). For a longer cord of length $L$ the stretch distance is longer so the spring constant is smaller in inverse proportion:

$$k=\left(\frac{5.00\text{ m}}{L}\right)\left(\frac{mg}{1.50\text{ m}}\right)=3.33mg/L$$

From the isolated system model,

$$\left(K+U_g+U_s\right)_i=\left(K+U_g+U_s\right)_f$$

$$0+mgy_i+0=0+mgy_f+\frac{1}{2}kx_f^2$$

$$mg\left(y_i-y_f\right)=\frac{1}{2}kx_f^2=\frac{1}{2}(3.33)\left(\frac{mg}{L}\right)x_f^2$$

here $y_i-y_f=55\text{ m}=L+x_f$. Substituting,

$$(55.0\text{ m})L=\frac{1}{2}(3.33)(55.0\text{ m}-L)^2$$

$$(55.0\text{ m})L=5.04\times10^3\text{ m}^2-(183\text{ m})L+1.67L^2$$

Suppressing units, we have

$$0 = 1.67L^2 - 238L + 5.04 \times 10^3 = 0$$

$$L = \frac{238 \pm \sqrt{238^2 - 4(1.67)(5.04 \times 10^3)}}{2(1.67)} = \frac{238 \pm 152}{3.33} = \boxed{25.8\text{ m}}$$

Only the value of $L$ less than 55 m is physical.

(b) From part (a), $k = 3.33\left(\frac{mg}{25.8\text{ m}}\right)$, with

$$x_{\max} = x_f = 55.0\text{ m} - 25.8\text{ m} = 29.2\text{ m}$$

From Newton's second law,

$$\sum F = ma: \qquad +kx_{\max} - mg = ma$$

$$3.33\frac{mg}{25.8\text{ m}}(29.2\text{ m}) - mg = ma$$

$$a = 2.77g = \boxed{27.1\text{ m/s}^2}$$

## ANSWERS TO EVEN-NUMBERED PROBLEMS

**P8.2** (a) $\Delta K + \Delta U = 0,\ v = \sqrt{2gh}$; (b) $v = \sqrt{2gh}$

**P8.4** (a) $1.85 \times 10^4$ m, $5.10 \times 10^4$ m; (b) $1.00 \times 10^7$ J

**P8.6** (a) 5.94 m/s, 7.67 m/s; (b) 147 J

**P8.8** (a) $\sqrt{\dfrac{2(m_1 - m_2)gh}{m_1 + m_2}}$; (b) $\dfrac{2m_1h}{m_1 + m_2}$

**P8.10** (a) $1.11 \times 10^9$ J; (b) 0.2

**P8.12** 2.04 m

**P8.14** (a) −168 J; (b) 184 J; (c) 500 J; (d) 148 J; (e) 5.65 m/s

**P8.16** (a) 650 J; (b) 588 J; (c) 0; (d) 0; (e) 62.0 J; (f) 1.76 m/s

**P8.18** (a) 22.0 J, $E = K + U$ = 30.0 J + 10.0 J = 40.0 J; (b) Yes; (c) The total mechanical energy has decreased, so a nonconservative force must have acted.

**P8.20** (a) $v_B$ = 1.65 m/s$^2$; (b) green bead, see P8.20 for full explanation

**P8.22** 3.74 m/s

**P8.24** (a) 0.381 m; (b) 0.371 m; (c) 0.143 m

**P8.26** (a) 24.5 m/s; (b) Yes. This is too fast for safety; (c) 206 m; (d) see P8.26(d) for full explanation

**P8.28** (a) $1.24 \times 10^3$ W; (b) 0.209

**P8.30** (a) 8.01 W; (b) see P8.30(b) for full explanation

**P8.32** $2.03 \times 10^8$ s, $5.64 \times 10^4$ h

**P8.34** 194 m

**P8.36** The power of the sports car is four times that of the older-model car.

**P8.38** (a) $5.91 \times 10^3$ W; (b) $1.11 \times 10^4$ W

**P8.40** (a) 854; (b) 0.182 hp; (c) This method is impractical compared to limiting food intake.

**P8.42** $\sim 10^2$ W

**P8.44** (a) 0.225 J; (b) −0.363 J; (c) no; (d) It is possible to find an effective coefficient of friction but not the actual value of $\mu$ since $n$ and $f$ vary with position.

**P8.46** (a) 2.49 m/s; (b) 5.45 m/s; (c) 1.23 m; (d) no; (e) Some of the kinetic energy of $m_2$ is transferred away as sound and to internal energy in $m_1$ and the floor.

**P8.48** We find that her arms would need to be 1.36 m long to perform this task. This is significantly longer than the human arm.

**P8.50** (a) 0.403 m or –0.357 m (b) From a perch at a height of 2.80 m above the top of a pile of mattresses, a 46.0-kg child jumps upward at 2.40 m/s. The mattresses behave as a linear spring with force constant 19.4 kN/m. Find the maximum amount by which they are compressed when the child lands on them; (c) 0.023 2 m; (d) This result is the distance by which the mattresses compress if the child just stands on them. It is the location of the equilibrium position of the oscillator.

**P8.52** (a) $\frac{1}{2}mv_f^2 - \frac{1}{2}mv_f^2$; (b) $-mgh - \left(\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2\right)$; (c) $\frac{1}{2}mv_f^2 - \frac{1}{2}mv_f^2 + mgh$

**P8.54** $\frac{\rho A v^3}{2}$; $F = \frac{\rho A v^2}{2}$; see P8.54 for full explanation

**P8.56** (a) 16.5 m; (b) See ANS. FIG. P8.56

**P8.58** Unrestrained passengers will fall out of the cars

**P8.60** (a) See P8.60(a) for full explanation; (b) see P8.60(b) for full explanation

**P8.62** (a) 0.378 m; (b) 2.30 m/s; (c) 1.08 m

**P8.64** 1.24 m/s

**P8.66** 48.2°

**P8.68** $\frac{3L}{5}$

**P8.70** The tension at the bottom is greater than the performer can withstand.

**P8.72** (a) 5R/2; (b) 6*mg*

**P8.74** (a) No, mechanical energy is not conserved in this case; (b) 77.0 m/s

**P8.76** 25.2 km/h and 27.0 km/h

**P8.78** (a) 21.0 m/s; (b) 16.1 m/s

**P8.80** (a) (627 N)$y$; (b) $U_s = 0$, $\frac{1}{2}(81\text{ N/m})(39.2\text{m} - y)^2$; (c) (627 N)$y$, (40.5 N/m) $y^2$ – (2 550 N)$y$ + 62 200 J; (d) See ANS. FIG. P7.78(d); (e) 10.0 m; (f) stable equilibrium, 31.5 m; (g) 24.1 m/s

**P8.82** (a) $\frac{1.60\text{ m}}{1 + 8.64\text{ N}^2/\text{F}^2}$; (b) 0.166 m; (c) 1.47 m; (d) $H \to 0$ as is reasonable; (e) H $\to$ 1.60 m; (f) $(0.800\text{ m})\left(1 - \frac{1}{\sqrt{1 + F^2/8.64\text{ N}^2}}\right)$; (g) 0.574 m; (h) 0.800 m

**P8.84** (a) $3.00\lambda$; (b) 7.42 m/s