Understanding the Concepts

6.6. The net work done on the piano is the same in each case. We are neglecting friction, and the work done by gravity is independent of the path taken by the piano to get from one place to another. Note that when the crew carries the piano, they must also do work on themselves to raise themselves from ground level to the third floor.

6.20. Yes. As the egg moves downward while making contact with the ground, the ground exerts an upward force on the egg, doing negative work on it (as the force is opposite to the direction of motion of the egg). This negative work causes the kinetic energy of the egg to decrease and eventually to vanish.

6.23. Suppose we choose the direction of the force as positive. In the original reference frame both the force and the velocity are positive, so \( W \) is also positive. In the reference frame of the moving observer, the force is still positive (as its orientation did not change), but the direction of motion of the object is now negative; so \( W \) becomes negative.

6.27. The net work done by a conservative force over any enclosed path is zero. This is not the case for the drag forces you encounter when you swim; otherwise as you complete one lap to return to your starting point you would need to have done no net work paddling the water (assuming that your initial and final speeds are both the same, say, zero), as there is no net negative work from the drag force that you need to overcome. That means that swimming would be effortless — no matter how long the lap is, as long as your return to your initial position. This is certainly not true. In reality, you need to keep paddling to overcome the drag forces, which always do negative work on you.

7.3. It means that the value of the gravitational potential energy of the person at the bottom of the well is below that at the sea level; so, for example, positive work must be done on the person in order to bring him to the sea level.

7.5. When dropped from rest the rubber ball has only gravitational potential energy. Ideally, if there is no loss of energy, the ball would return to the initial height, whereupon it regains all of its original potential energy back. In reality, of course, one would always expect some loss of mechanical energy, due to air friction as well as during the collision with the floor (in terms of heat and sound). So the ball will not be able to return to the same height since it does not have that much potential energy left. A ball thrown down with a large initial speed has a significant amount of initial kinetic energy, which can be converted into gravitational potential energy, allowing it to attain a much greater height upon rebounding.
7.15. As the object slides along the slope, the direction of the normal force is perpendicular to the slope, so it does zero work on the object and becomes irrelevant when we calculate the total work done on the object. The only force doing non-zero work on the object is the gravitational force, which is conservative. The system is therefore a conservative one. This can be verified by checking to make sure that $E_i = E_f$.

7.17. Zeros of the potential energy have absolutely nothing to do with zeros of the force. Zeros of the potential energy depend on arbitrary additive constants in that energy, not on any property of the force. These zeros have no physical significance. Zeros of the force are located at places where the derivative of the potential energy is zero; that is, at locations where the potential energy is not changing. Force zeros have a very real physical significance.

**Solve yourself problems**

6.7. Because there is no acceleration, we have $F_N = mg$ and $F = f_k = \mu_k mg$.

(a) The work done by the man is

$$W_p = F \Delta x = 0.4(40 \text{ kg})(9.8 \text{ m/s}^2)(1.5 \text{ m}) = 2.4 \times 10^2 \text{ J}.$$

(b) The friction force also does work (negative).

(c) $W_{\text{net}} = W_p + W_f = \Delta K = 0$.

6.45. The work of the spring changes the kinetic energy:

$$W_{sp} = \int (-kx) \, dx = -\frac{1}{2}k(0)^2 + \frac{1}{2}k(L)^2 = \frac{1}{2}mv^2 - 0; \text{ or } \frac{1}{2}kL^2 = \frac{1}{2}mv^2;$$

$(60 \text{ N/m})(0.07 \text{ m})^2 = (4 \times 10^{-3} \text{ kg})v^2$, which gives $v = 8.6 \text{ m/s}$.

6.68. We convert the speed units: $(100 \text{ km/h})/(3600 \text{ s/h}) = 27.8 \text{ m/s}$.

The required work is $\Delta W = \Delta K = \frac{1}{2}m(v^2 - 0)$;

From $P = \Delta W/\Delta t$ we find

$$\Delta t = \frac{\Delta W}{P} = \frac{1}{2}(1200 \text{ kg})(27.8 \text{ m/s})^2/[(80 \text{ hp})(746 \text{ W/hp})] = 7.8 \text{ s}.$$
7.19. Far away, $F = -\frac{dU}{dx} = 0$.

In the attractive region, $\frac{dU}{dx}$ must be positive.

In the repulsive region, $\frac{dU}{dx}$ must be negative.

At very small separations, $|\frac{dU}{dx}|$ must get very large.

7.31. We choose $y = 0$ at the sea. If there is no drag, energy is conserved:

$E = \frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f$;

$\frac{1}{2}m(125 \text{ m/s})^2 + m(9.8 \text{ m/s}^2)(68 \text{ m}) = \frac{1}{2}mv_f^2 + m(9.8 \text{ m/s}^2)(0)$, which gives $v_f = 130 \text{ m/s}$.

When fired at an angle, the gravitational energy change is the same; the final speed will be the same. The direction of the velocity will be different.

7.47. The work done by the nonconservative drag forces changes the energy of the system:

$W_{nc} = \Delta(K+U) = (K_f + U_f) - (K_i + U_i) = (\frac{1}{2}mv_f^2 + 0) - (0 + mgh_i)$

$= \frac{1}{2}(75 \text{ kg})(5.0 \text{ m/s})^2 - (75 \text{ kg})(9.8 \text{ m/s}^2)(85 \text{ m}) = -6.2 \times 10^4 \text{ J}$.

**Hand-in Problems**

6.38 The normal force does no work, so the work-energy theorem gives

$W_{net} = \Delta K$, or $W_g + W_f = \frac{1}{2}m(v^2 - v_0^2)$, which becomes

$(32 \text{ kg})(9.8 \text{ m/s}^2)(10 \text{ m}) \sin 17^\circ + W_f = \frac{1}{2}(32 \text{ kg})(2.5 \text{ m/s}^2) - 0$,

from which we get $W_f = -8.2 \times 10^2 \text{ J}$.

Because $W_f = -m_i(\text{mg cos } \theta)L$, we have

$-8.2 \times 10^2 \text{ J} = -m_i(32 \text{ kg})(9.8 \text{ m/s}^2)(\text{cos } 17^\circ)$

(10 m), which gives $\mu_k = 0.27$. 
6.69. Because the velocity is uniform, for $\Sigma F = ma$ for the sled, we can write

x-component: $F - \mu_k F_N = 0$;

y-component: $F_N - mg = 0$, which gives

$F = \mu_k mg = (0.03)(5000 \text{ N}) = 150 \text{ N}.$

The maximum power will produce the maximum speed:

$P_{\text{max}} = Fv_{\text{max}}$;

$(1 \text{ hp})(746 \text{ W/hp}) = (150 \text{ N})v_{\text{max}},$

which gives $v_{\text{max}} = 5.0 \text{ m/s}$.

On an incline, we have:

x-component: $F - mg \sin \theta - \mu_k F_N = 0$;

y-component: $F_N - mg \cos \theta = 0$, which gives

$F = mg (\sin \theta + \mu_k \cos \theta) = (5000 \text{ N})(\sin 5^\circ + 0.03 \cos 5^\circ) = 585 \text{ N}.$

The maximum power will produce the maximum speed on the incline:

$P_{\text{max}} = Fv_{\text{max}}$;

$(1 \text{ hp})(746 \text{ W/hp}) = (585 \text{ N})v_{\text{max}},$ which gives $v_{\text{max}} = 1.3 \text{ m/s}$.

6.90. (a) With $F_N = mg$, we have $f_k = \mu_k mg = 0.55(1100 \text{ kg})(9.8 \text{ m/s}^2) = 5.9 \times 10^3 \text{ N}$.

(b) Because friction opposes the motion, we have

$W_f = -f_k \Delta x = -(5.9 \times 10^3 \text{ N})(48 \text{ m}) = -2.8 \times 10^5 \text{ J}.$

(c) Friction is the only force that does work, so we have

$W_{\text{net}} = W_f = \Delta K; \quad -2.8 \times 10^5 \text{ J} = 0 - \frac{1}{2}(1100 \text{ kg})v_0^2,$

which gives $v_0 = 23 \text{ m/s} = 51 \text{ mi/h.}$
7.13. We choose \( y = 0 \) at the relaxed position of the spring and denote the height of
release by \( h \) and the magnitude of the compression of the spring by \( \Delta y \).

Because the energy is conserved, we have

\[
E = K + U_g + U_{\text{spring}} = \text{constant};
\]
\[
0 + mgh + 0 = 0 + mg(-\Delta y) + \frac{1}{2} k(-\Delta y)^2;
\]
\[
(15 \text{ kg})(9.8 \text{ m/s}^2)(6.0 \text{ m}) = (15 \text{ kg})(9.8 \text{ m/s}^2)(-\Delta y) + \frac{1}{2} (10^4 \text{ N/m})(\Delta y)^2.
\]

This is a quadratic equation for \( \Delta y \), from which we get \( \Delta y = 0.43 \text{ m}, -0.41 \text{ m} \).

From our choice of \( \Delta y \) as a magnitude, we select the positive value: \( \Delta y = 0.43 \text{ m} \).

For the man, the numbers become

\[
(60 \text{ kg})(9.8 \text{ m/s}^2)(15 \text{ m}) = (60 \text{ kg})(9.8 \text{ m/s}^2)(-\Delta y) + \frac{1}{2} (10^4 \text{ N/m})(\Delta y)^2, \quad \text{which gives } \Delta y = 0.48 \text{ m}.
\]

The greater decrease in gravitational potential energy requires a greater spring potential energy.

7.61. We choose \( y = 0 \) at the bottom of the loop.

With no friction, energy is conserved.

The initial (and constant) energy is

\[
E = \frac{1}{2}mv_1^2 + mgh_1 = 0 + mgh_1 = mgh_1.
\]

We find the speed at a height \( h \) from

\[
\frac{1}{2}mv^2 + mgh = mgh_1; \quad v = \sqrt{2g(h_1 - h)}.
\]

(a) The skier starts from rest: \( v_1 = 0 \).

\[
v_2 = \sqrt{2g(h_1 - h_2)} = \sqrt{2(98 \text{ m/s}^2)(18 \text{ m} - 15 \text{ m})} = 7.7 \text{ m/s}.
\]

\[
v_3 = \sqrt{2g(h_1 - h_3)} = \sqrt{2(98 \text{ m/s}^2)(18 \text{ m} - 7 \text{ m})} = 14.7 \text{ m/s}.
\]
(b) At $x_3$ gravity is down and the normal force must be up.

These two provide the centripetal acceleration: $mg - F_N = m v_3^2 / R$, so the normal force is

$$F_N = m(g - v_3^2 / R)$$

$$= m[g - 2g(h_1 - h_3)/h_3]$$

$$= mg(3 - 2h_1/h_3) = mg[3 - 2(18 \text{ m})/7 \text{ m}],$$

which is negative.

The normal force cannot be negative (it can not pull on the skier), so the skier leaves the surface.

We set $F_N$ to its minimum value (zero) to find the maximum value of $h_1$ at which the skier stays on:

$$F_N = 0; 3 - 2h_1/h_3 = 0,$$

which gives $h_1 = 3h_3/2 = 3(7 \text{ m})/2 = 10.5 \text{ m}$. 