Chapter 5: Work, Energy, Power, and Society

Mini Investigation: Pizza Pan Half-Pipe, page 221

A. The final positions are slightly less than the initial positions of the marble in each case. Increasing the initial height of the marble does not affect the difference between the initial and final positions of the marble.

B. Since energy is not being added to the system, the potential energy the marble has before it is released gets translated into kinetic energy of movement. The amount of energy of the marble at the initial position and finally position should be the same but it is not. The difference in the final position of the marble could be due to friction.

Section 5.1: Work

Tutorial 1 Practice, page 223

1. Given: Choose right as positive.
$m = 0.50$ kg; $v_i = +3.0$ m/s; $\Delta t = 2.0$ s;
$a = +1.2$ m/s^2; $F_f = 0$ N

Required: F_a; Δd; W

(a) The force exerted by the string on the cart:

Analysis: $F_{net} = ma$

Solution:

$$\begin{aligned}
F_{net} &= ma \\
F_a - F_f &= ma \\
F_a - 0 &= (0.50 \text{ kg})(1.2 \text{ m/s}^2) \\
&= 0.6 \text{ kg•m/s}^2 \\
&= 0.6 \text{ N} \\
F_a &= 0.60 \text{ N}
\end{aligned}$$

Statement: The string exerts a force of 0.60 N on the cart.

(b) The displacement of the cart:

Analysis: $\Delta d = v_i\Delta t + \frac{1}{2}a\Delta t^2$

Solution: First, find v_2.

$$\begin{aligned}
a &= \frac{v_2 - v_1}{\Delta t} \\
v_2 &= a\Delta t + v_1 \\
&= \left(1.2 \frac{\text{m}}{\text{s}^{\cancel{2}}}\right)(2.0 \cancel{\text{s}}) + 3.0 \text{ m/s} \\
&= 2.4 \text{ m/s} + 3.0 \text{ m/s} \\
&= 5.4 \text{ m/s}
\end{aligned}$$

Then, find Δd.

$$\begin{aligned}
\Delta d &= \left(\frac{v_1 + v_2}{2}\right)\Delta t \\
&= \left(\frac{3.1 \frac{\text{m}}{\cancel{\text{s}}} + 5.4 \frac{\text{m}}{\cancel{\text{s}}}}{2}\right)(2.0 \cancel{\text{s}}) \\
\Delta d &= 8.4 \text{ m}
\end{aligned}$$

Statement: The displacement of the cart is 8.4 m.

(c) The mechanical work done by the string on the cart:

Analysis: $W = F\Delta d$

Solution:

$$\begin{aligned}
W &= F\Delta d \\
&= (0.60 \text{ N})(8.4 \text{ m}) \\
&= 5.04 \text{ N•m} \\
&= 5.04 \text{ J} \\
W &= 5.0 \text{ J}
\end{aligned}$$

$$\begin{aligned}
W &= F\Delta d \\
&= (0.60 \text{ N})(8.4 \text{ m}) \\
&= 5.04 \text{ N•m} \\
&= 5.04 \text{ J} \\
W &= 5.0 \text{ J}
\end{aligned}$$

Statement: The mechanical work done by the string on the cart is 5.0 J.

Tutorial 2 Practice, page 225

1. Given: $F = 125$ N; $\theta = 40.0°$; $\Delta d = 12.0$ m

Required: W

Analysis: $W = F_a(\cos\,\theta)\Delta d$

Solution:
$$\begin{aligned}
W &= F(\cos\theta)\Delta d \\
&= (125 \text{ N})(\cos 40.0°)(12.0 \text{ m}) \\
&= 1149 \text{ N•m} \\
&= 1149 \text{ J} \\
W &= 1.15\times 10^3 \text{ J, or } 1.15 \text{ kJ}
\end{aligned}$$

Statement: The person does 1.15×10^3 J, or 1.15 kJ, of mechanical work on the lawnmower.

2. Solution: Both the work done by the normal force and the work done by gravity are zero. Both of these forces are perpendicular to the direction of motion and therefore do no work on the toboggan.

Statement: The work done by the normal force and the work done by gravity are zero.

Tutorial 3 Practice, page 226

1. (a) Since the brick wall does not move while the student is leaning on it, there is no acceleration. If there is no acceleration, there is no net force. Therefore, no work is done.
(b) Since the space probe is coasting at a constant velocity toward the planet, there is no net force acting on it. Therefore, there is no work done on it.
(c) A textbook sitting on a shelf experiences no motion. Since there is no motion, there is no work being done.

Tutorial 4 Practice, page 227

1. Given: $F_a = 4.5$ N; $F_f = 2.8$ N; $\Delta d = 1.3$ m
Required: W_{net}
Analysis: $W = F\Delta d$
Solution:

$$\begin{aligned}
W_{net} &= W_a + W_f \\
&= F_a(\cos 0°)\Delta d + F_f(\cos 180°)\Delta d \\
&= (4.5\text{ N})(1)(1.3\text{ m}) + (2.8\text{ N})(-1)(1.3\text{ m}) \\
&= 5.85\text{ N}\bullet\text{m} - 3.64\text{ N}\bullet\text{m} \\
&= 2.21\text{ N}\bullet\text{m} \\
W_{net} &= 2.21\text{ J}
\end{aligned}$$

Statement: The net work done on the bowl is 2.2 J.
2. Given: Choose up as positive.
$m = 450$ kg; $\Delta d = +12$ m; $g = 9.8$ N/kg
Required: W
Analysis:

$$W = F\Delta d$$
$$F_a = F_g$$
$$F_g = mg$$

Solution: Find F_g.

$$\begin{aligned}
F_g &= mg \\
&= (450\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right) \\
&= 4410\text{ N} \\
F_a &= 44.10\text{ N}
\end{aligned}$$

$$\begin{aligned}
W_a &= F_a(\cos\ 0°)\Delta d \\
&= (4410\text{ N})(12\text{ m}) \\
&= 52\ 920\text{ N}\bullet\text{m} \\
&= 52.92\text{ kJ} \\
W_a &= 53\text{ kJ}
\end{aligned}$$

Statement: The mechanical work done by the crane is 53 kJ.

Mini Investigation: Human Work, page 228

Answers may vary. Sample answers.
A. The amount of work I did to lift the book was 14.11 J. The amount of work I did to lift the shoe was 3.92 J. It took 10.2 J more to lift the book.
B. Since the shoe is lighter than the book, the shoe should take less work to lift. The book's mass is three times the mass of the shoe. To lift the shoe, I predicted it would take one-third the amount of work to lift the book. My prediction was fairly accurate.
C. Given: $W_{shoe} = 14.11$ J; $F_{g\ shoe} = 4.9$ N
Required: Δd
Analysis: $W = F\,\Delta d$
Solution:

$$\begin{aligned}
W &= F\Delta d \\
\Delta d &= \frac{W}{F} \\
&= \frac{14.11\text{ J}}{4.9\text{ N}} \\
&= 2.88\text{ m} \\
\Delta d &= 2.9\text{ m}
\end{aligned}$$

Statement: In order for the work to lift the shoe to equal the work to lift the book, the shoe must be lifted 2.9 m.

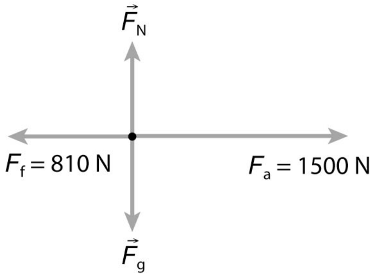
Section 5.1 Questions, page 229

1. Given: Choose the direction of motion to be positive.
$F = 25.0$ N; $\Delta d = 13.0$ m
Required: W
Analysis: $W = F\Delta d$
Solution:

$$\begin{aligned}
W &= F\Delta d \\
&= (25.0\text{ N})(13.0\text{ m}) \\
&= 325\text{ N}\bullet\text{m} \\
W &= 325\text{ J}
\end{aligned}$$

Statement: The work done by the applied force is 325 J.

2.



Given: $F_a = 1500$ N; $\theta_a = 0°$ (acting forwards); $F_f = 810$ N; $\theta_f = 180°$ (acting backwards); $\Delta d = 12$ m

Required: W_a; W_f; W_N; W_g

Analysis: $W = F(\cos\theta)\Delta d$

(a) The work done by the tow truck force on the car:

Solution:
$$\begin{aligned} W_a &= F_a(\cos\ \theta_a)\Delta d \\ &= (1500\text{ N})\ (\cos 0°)\ (12\text{ m}) \\ &= 18\ 000\text{ N•m} \\ W_a &= 18\text{ kJ} \end{aligned}$$

Statement: The work done by the force of the tow truck on the car is 18 kJ.

(b) The work done by the force of friction:

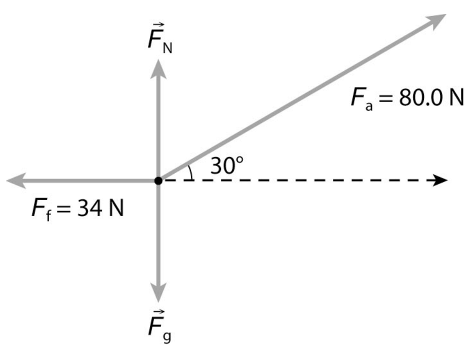
Solution:
$$\begin{aligned} W_f &= F_f(\cos\theta_f)\Delta d \\ &= (810\text{ N})(\cos 180°)(12\text{ m}) \\ &= -9720\text{ N•m} \\ &= -9720\text{ J} \\ W_f &= -9.7\text{ kJ} \end{aligned}$$

Statement: The work done by the force of friction is –9.7 kJ.

(c) The work done by the normal force is 0 J, since the normal force acts perpendicular to the direction of motion. ($\cos 90° = 0$)

(d) The work done by the force of gravity is 0 J, since gravity acts perpendicular to the direction of motion. ($\cos 90° = 0$)

3.



Given: $F_a = 80.0$ N; $\theta_a = 30.0°$; $F_f = 34$ N; $\theta_f = 180°$ (acting backwards); $\Delta d = 12$ m

Required: W_a; W_T

Analysis: $W = F(\cos\theta)\Delta d$; $W_T = W_a + W_f$

(a) The mechanical work done by the child on the wagon:

Solution:
$$\begin{aligned} W_a &= F_a(\cos\theta_a)\Delta d \\ &= (80.0\text{ N})(\cos 30.0°)(12\text{ m}) \\ &= 831.4\text{ N•m} \\ &= 831.4\text{ J} \\ W_a &= 830\text{ J} \end{aligned}$$

Statement: The mechanical work done by the child on the wagon is 830 J.

(b) The total work done on the wagon:

Solution:
$$\begin{aligned} W_T &= W_a + W_f \\ &= 831.4\text{ J} + F_f(\cos\theta_f)\Delta d \\ &= 831.4\text{ J} + (34\text{ N})(\cos 180°)(12\text{ m}) \\ &= 831.4\text{ N•m} - 408\text{ N•m} \\ &= 423.4\text{ N•m} \\ &= 423.4\text{ J} \\ W_T &= 420\text{ J} \end{aligned}$$

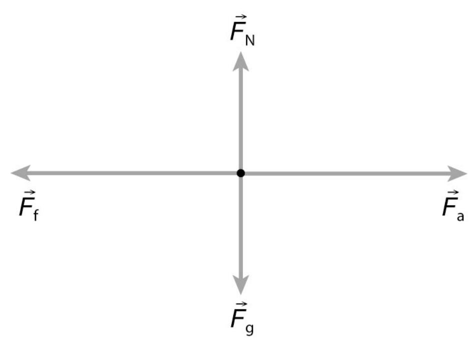
Statement: The total work done on the wagon is 420 J.

4. Given: $W_a = 250$ J; $\theta_a = 0°$; $\Delta d = 12$ m; $\theta_f = 180°$ (acting backwards)

Required: F_a; F_f; W_f

Analysis: $W = F(\cos\theta)\Delta d$

(a)



(b) The tension in the rope:

Solution:
$$\begin{aligned} W_a &= F_a(\cos\theta)\Delta d \\ F_a &= \frac{W_a}{(\cos\theta_a)\Delta d} \\ &= \frac{250\text{ J}}{(\cos 0°)(12\text{ m})} \\ &= 20.83\text{ J/m} \\ &= 20.83\text{ N} \\ F_a &= 21\text{ N} \end{aligned}$$

Statement: The tension in the rope is 21 N.

(c) Since the box is moving at a constant velocity, the forces acting on the box are balanced (the tension in the rope is balanced by the frictional force, and gravity is balanced by the normal force). Therefore, the force of friction is –21 N. There is also no net work done since the velocity of the box remains constant. Therefore, the work done by the force of friction is –250 J.

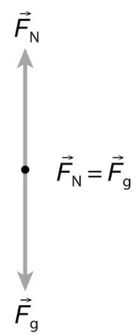
5. Given: Choose the direction up as positive.
m = 62 kg; $\theta_N = 0°$; v = +4.0 m/s; $\theta_g = 180°$;
Δt = 5.0 s; g = 9.8 N/kg

Required: W_N; W_g

Analysis:

$$W = F(\cos\theta)\Delta d$$
$$d = v\Delta t$$
$$F_g = mg$$

(a)



(b) The work done by the normal force on the person:

Solution:

$$\begin{aligned} W_N &= F_N\left(\cos\theta_N\right)\Delta d \\ &= (mg)(\cos\theta_N)(v\Delta t) \\ &= (62\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(\cos 0°)\left(+4.0\ \frac{\text{m}}{\cancel{\text{s}}}\right)(5.0\ \cancel{\text{s}}) \\ &= 12\ 152\ \text{N•m} \\ &= 12\ 152\ \text{J} \\ W_N &= 12\ \text{kJ} \end{aligned}$$

Statement: The work done by the normal force on the person is 12 kJ.

(c) The work done by the force of gravity on the person: Since the elevator is moving at a constant velocity, the forces are balanced. The work done by the force of gravity on the person is –12 kJ, since gravity is opposing motion.

(d) If the direction of the elevator were reversed, then the work done by gravity would be +12 kJ, and the work done by the normal force would be –12 kJ. This is due to the fact that the angles would be reversed: $\theta_g = 0°$ and $\theta_N = 180°$.

6. Given: F vs. Δd graph; Δd = 0.5 m

Required: W

Analysis: W = area under F vs. Δd graph

Solution:

$$\begin{aligned} W &= \text{area under } F\Delta d \text{ graph (rectangle)} \\ &= bh \\ &= (0.5\ \text{m})(4\ \text{N}) \\ &= 2.0\ \text{N•m} \\ &= 2.0\ \text{J} \\ W &= 2\ \text{J} \end{aligned}$$

Statement: The work done on the cart by the force sensor is 2 J.

7. Given: m = 2.0 kg; $\theta_a = 0°$; v_i = 0.0 m/s;
$\theta_g = 180°$; a = 2.2 m/s^2; g = 9.8 N/kg; Δt = 3.0 s

Required: Δd; W_a; W_g; W_T; F_{net}; W_{net}

Analysis:

$$\Delta d = \left(\frac{v_i + v_f}{2}\right)\Delta t$$
$$v_f = at + v_i$$
$$F_g = mg$$
$$W = F(\cos\theta)\Delta d$$
$$F_{net} = ma$$

(a) The displacement of the bucket:

Solution:

$$\begin{aligned} \Delta d &= \left(\frac{v_i + (at + v_i)}{2}\right)\Delta t \\ &= \left(\frac{0\ \frac{\text{m}}{\text{s}} + \left(2.2\ \frac{\text{m}}{\text{s}^{\cancel{2}}}\right)(3.0\ \cancel{\text{s}}) + 0\ \frac{\text{m}}{\text{s}}}{2}\right)3.0\ \text{s} \\ &= \left(\frac{6.6\ \frac{\text{m}}{\cancel{\text{s}}}}{2}\right)3.0\ \cancel{\text{s}} \\ \Delta d &= 9.9\ \text{m} \end{aligned}$$

Statement: The displacement of the bucket is 9.9 m.

(b) The work done by gravity and the work done by the rope:
Solution:

$$\begin{aligned}W_g &= F_g(\cos\theta)\,\Delta d\\ &= (mg)(\cos\theta)(\Delta d)\\ &= (2.0\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(\cos 180°)(9.9\text{ m})\\ &= -194.0\text{ N•m}\\ &= -194.0\text{ J}\\ W_g &= -190\text{ J}\end{aligned}$$

To find W_a, calculate F_a.

$$\begin{aligned}F_{net} &= ma\\ F_a - F_g &= ma\\ F_a &= ma + mg\\ &= (2.0\text{ kg})(2.2\text{ m/s}^2) + (2.0\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)\\ &= 4.4\text{ kg•m/s}^2 + 19.6\text{ N}\\ F_a &= 24.0\text{ N}\end{aligned}$$

$$\begin{aligned}W_a &= F_a\left(\cos\theta_a\right)\Delta d\\ &= (24.0\text{ N})(\cos 0°)(9.9\text{ m})\\ &= 237.6\text{ N•m}\\ &= 237.6\text{ J}\\ W_a &= 240\text{ J}\end{aligned}$$

Statement: The work done by gravity is –190 J, and the work done by the rope is 240 J.

(c) The total mechanical work done on the bucket:
Solution:

$$\begin{aligned}W_T &= W_a + W_g\\ &= 237.6\text{ J} - 194.0\text{ J}\\ &= 43.6\text{ J}\\ W_T &= 44\text{ J}\end{aligned}$$

Statement: The total mechanical work done on the bucket is 44 J.

(d) The net force acting on the bucket and the mechanical work done by the net force:
Solution:

$$\begin{aligned}F_{net} &= ma\\ &= (2.0\text{ kg})(2.2\text{ m/s}^2)\\ &= 4.40\ \frac{\text{kg•m}}{\text{s}^2}\\ &= 4.40\text{ N}\\ F_{net} &= 4.4\text{ N}\end{aligned}$$

$$\begin{aligned}W_{net} &= F_{net}\left(\cos\theta_{net}\right)\Delta d\\ &= (4.40\text{ N})(\cos 0°)(9.9\text{ m})\\ &= 43.56\text{ N•m}\\ &= 43.56\text{ J}\\ W_{net} &= 44\text{ J}\end{aligned}$$

Statement: The net force acting on the bucket is 4.4 N. The mechanical work done by the net force is 44 J. This is the same value calculated in (c).

8. (a) No mechanical work is done on a box sitting on a shelf. The box is not moving, so the net force is zero. If the net force is zero, then the work done is also zero.

(b) If an employee pulls on the box with a horizontal force and nothing happens, then no mechanical work is done. Since nothing happens, the displacement is zero. If the displacement is zero, then the work done is also zero.

(c) Initially, work is done on the box to get it moving. However, once the box is sliding down the frictionless rollers, the box is moving at a constant velocity. If the velocity is constant, then there is no acceleration. If there is no acceleration, the net force is zero. If the net force is zero, then the work done is also zero.

9. Given: F vs. Δd graph
Required: W_A; W_B; W_C; W_T
Analysis: W = area under F vs. Δd graph;
$W_T = W_A + W_B + W_C$
(a) The work done by the spring in sections A, B, and C:
Solution:

$$\begin{aligned} W_A &= \text{area under } F\Delta d \text{ graph (rectangle A)} \\ &= bh \\ &= (2\text{ m})(5\text{ N}) \\ &= 10\text{ N}\bullet\text{m} \\ W_A &= 10\text{ J} \end{aligned}$$

$$\begin{aligned} W_B &= \text{area under } F\Delta d \text{ graph (triangle B)} \\ &= \frac{bh}{2} \\ &= \frac{(1\text{ m})(5\text{ N})}{2} \\ &= 2.5\text{ N}\bullet\text{m} \\ W_B &= 2.5\text{ J} \end{aligned}$$

$$\begin{aligned} W_C &= \text{area under } F\Delta d \text{ graph (triangle C)} \\ &= \frac{bh}{2} \\ &= \frac{(1\text{ m})(-5\text{ N})}{2} \\ &= -2.5\text{ N}\bullet\text{m} \\ W_C &= -2.5\text{ J} \end{aligned}$$

Statement: The work done by the spring in sections A, B, and C is, respectively, 10 J, 2.5 J, and –2.5 J.

(b) The total work done by the spring:
Solution:

$$\begin{aligned} W_T &= W_A + W_B + W_C \\ &= 10\text{ J} + 2.5\text{ J} - 2.5\text{ J} \\ W_T &= 10\text{ J} \end{aligned}$$

Statement: The total work done by the spring is 10 J.
(c) The work done in section C must be negative because the force is negative. It is applied in the direction opposite to that of the motion.
10. The total work done on one object by another can be calculated by using the mechanical work equation, $W = F(\cos \theta)\Delta d$ or by calculating the area under the force vs. displacement graph.
11. (a) If a force is perpendicular to the displacement, then the angle is 90º. The cosine of 90º is zero, so the product of $F(\cos \theta)\Delta d$ is also zero.
(b) If a force acts opposite to the displacement, then the angle is 180º. The cosine of 180º is –1, so the product of $F(\cos \theta)\Delta d$ is also negative.