Section 5.2: Energy

Tutorial 1 Practice, page 231

1. Given: m = 70.0 kg; v = 12 m/s
Required: E_k
Analysis: $E_k = \frac{1}{2}mv^2$
Solution:

$$\begin{aligned}
E_k &= \frac{mv^2}{2} \\
&= \frac{(70.0\text{ kg})(12\text{ m/s})^2}{2} \\
&= 5040\ \frac{\text{kg•m}^2}{\text{s}^2} \\
&= 5040\text{ J} \\
E_k &= 5.0\text{ kJ}
\end{aligned}$$

Statement: The kinetic energy of the runner is 5.0 kJ.

2. Given: E_k = 4.2 J; v = 5.0 m/s
Required: m
Analysis: $E_k = \frac{1}{2}mv^2$
Solution:

$$\begin{aligned}
E_k &= \frac{mv^2}{2} \\
m &= \frac{2E_k}{v^2} \\
&= \frac{2(4.2\text{ J})}{(5.0\text{ m/s})^2} \\
&= 0.336\ \frac{\text{J•s}^2}{\text{m}^2} \\
&= 0.336\text{ kg} \\
m &= 0.34\text{ kg}
\end{aligned}$$

Statement: The mass of the cart is 0.34 kg.

3. Given: E_k = 30.0 J; m = 150 g = 0.15 kg
Required: v
Analysis: $E_k = \frac{1}{2}mv^2$
Solution:

$$\begin{aligned}
E_k &= \frac{mv^2}{2} \\
v &= \sqrt{\frac{2E_k}{m}} \\
&= \sqrt{\frac{2(30.0\text{ J})}{0.15\text{ kg}}} \\
v &= 20\text{ m/s}
\end{aligned}$$

Statement: The speed of the bird is 20 m/s (correct to two significant digits).

Tutorial 2 Practice, page 232

1. Given: m =1300 kg; v_i = 0 m/s; v_f = 14 m/s; Δd = 82 m
Required: W; F_{net}
Analysis: $W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$; $W_{net} = F_{net}\Delta d$

(a) Net work done on the car:
Solution:

$$\begin{aligned}
W_{net} &= \frac{mv_f^2}{2} - \frac{mv_i^2}{2} \\
&= \frac{(1300\text{ kg})(14\text{ m/s})^2}{2} - \frac{(1300\text{ kg})(0\text{ m/s})^2}{2} \\
&= 127\ 400\ \frac{\text{kg•m}^2}{\text{s}^2} - 0 \\
&= 127\ 400\text{ J} \\
&= 127.4\text{ kJ} \\
W_{net} &= 130\text{ kJ}
\end{aligned}$$

Statement: The net work done on the car is 130 kJ.

(b) Net force acting on the car:
Solution:

$$\begin{aligned}
W_{net} &= F_{net}\Delta d \\
F_{net} &= \frac{W_{net}}{\Delta d} \\
&= \frac{127\ 400\text{ J}}{82\text{ m}} \\
&= 1553.6\text{ J/m} \\
&= 1554\text{ N} \\
F_{net} &= 1.6 \times 10^3\text{ N}
\end{aligned}$$

Statement: The net force acting on the car is 1.6×10^3 N.

2. Given: m = 52 kg; v_i = 11 m/s; v_f = 0 m/s; Δd = 8.0 m
Required: F_{net}
Analysis: $W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$; $W_{net} = F_{net}\Delta d$

(a) The net force on the skater:
Solution:

$$\begin{aligned}
W_{net} &= \frac{mv_f^2}{2} - \frac{mv_i^2}{2} \\
&= \frac{(52\text{ kg})(0\text{ m/s})^2}{2} - \frac{(52\text{ kg})(11\text{ m/s})^2}{2} \\
&= 0\ \frac{\text{kg•m}^2}{\text{s}^2} - 3146\ \frac{\text{kg•m}^2}{\text{s}^2} \\
&= -3146\text{ J} \\
W_{net} &= -3.146\text{ kJ}
\end{aligned}$$

$$W_{net} = F_{net}\Delta d$$
$$F_{net} = \frac{W_{net}}{\Delta d}$$
$$= \frac{-3146 \text{ J}}{8.0 \text{ m}}$$
$$= -393.2 \text{ J/m}$$
$$= -393.2 \text{ N}$$
$$F_{net} = -3.9 \times 10^2 \text{ N}$$

Statement: The net force on the skater is -3.9×10^2 N.

(b) The net work done on the skater must be negative for these two reasons. First, the object is slowing down and losing kinetic energy. Since the change in kinetic energy is negative, the net work done must be negative. Second, the force of friction is causing the skater to slow down. Friction always acts in the direction opposing motion. Since the force and motion are in opposite directions, the net work done is negative. The net force works in a backwards direction.

Tutorial 3 Practice, page 234

1. Given: $m = 58$ kg; $h_{top} = 6.0$ m; $h_{landing} = 3.0$ m; $h_{ground} = 0$ m; $g = 9.8$ N/kg; Ground is reference level for height.

Required: $E_{g\ top}$; $E_{g\ landing}$; $E_{g\ ground}$

Analysis: $E_g = mgh$

(a) Gravitational potential energy at top, landing, and ground level:

Solution:

$$E_{g\ top} = mgh_{top}$$
$$= (58\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(6.0 \text{ m})$$
$$= 3410.4 \text{ N•m}$$
$$= 3410.4 \text{ J}$$
$$E_{g\ top} = 3400 \text{ J}$$

$$E_{g\ landing} = mgh_{landing}$$
$$= (58\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(3.0 \text{ m})$$
$$= 1705.2 \text{ N•m}$$
$$= 1705.2 \text{ J}$$
$$E_{g\ landing} = 1700 \text{ J}$$

$$E_{g\ bottom} = mgh_{bottom}$$
$$= (58\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(0 \text{ m})$$
$$E_{g\ bottom} = 0 \text{ J}$$

Statement: The gravitational potential energy at the top, landing, and bottom of stairs is, respectively, 3400 J, 1700 J, and 0 J.

(b) As you go down a flight of stairs, the gravitational potential energy decreases. As you climb a flight of stairs, the gravitational potential energy increases.

Section 5.2 Questions, page 235

1. Given: $m = 610$ kg; $E_k = 40.0$ kJ = 40 000 J

Required: v

Analysis: $E_k = \frac{1}{2}mv^2$

Solution:

$$E_k = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2E_k}{m}}$$
$$= \sqrt{\frac{2(40\ 000 \text{ J})}{610 \text{ kg}}}$$
$$= 11.45 \text{ m/s}$$
$$v = 11 \text{ m/s}$$

Statement: The speed of the bobsleigh is 11 m/s.

2. Given: $m = 0.160$ kg; $v_i = 0$ m/s; $v_f = 22$ m/s; $\Delta d = 1.2$ m

Required: E_k; F_{net}

Analysis:

$$E_k = \frac{1}{2}mv^2$$
$$F_{net} = ma$$
$$v_f^2 = v_i^2 + 2a\Delta d$$
$$W_{net} = E_{kf} - E_{ki}$$
$$W_{net} = F_{net}\Delta d$$

(a) The final kinetic energy of the puck:

Solution:

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(0.160 \text{ kg})(22 \text{ m/s})^2$$
$$= 38.72\ \frac{\text{kg•m}^2}{\text{s}^2}$$
$$= 38.72 \text{ J}$$
$$E_k = 39 \text{ J}$$

Statement: The final kinetic energy of the puck is 39 J.

(b) The average net force on the puck using two different methods:
Solution:
Method 1:
Step 1. Calculate the acceleration using kinematics.

$$v_f^2 = v_i^2 + 2a\Delta d$$
$$a = \frac{v_f^2 - v_i^2}{2\Delta d}$$
$$= \frac{(22 \text{ m/s})^2 - (0 \text{ m/s})^2}{(2)(1.2 \text{ m})}$$
$$= \frac{484 \text{ m}^{\cancel{2}}/\text{s}^2}{2.4 \cancel{\text{m}}}$$
$$a = 201.7 \text{ m/s}^2$$

Step 2. Calculate the net force using Newton's second law of motion.

$$F_{net} = ma$$
$$= (0.160 \text{ kg})(201.7 \text{ m/s}^2)$$
$$= 32.27 \frac{\text{kg}\bullet\text{m}^2}{\text{s}^2}$$
$$= 32.27 \text{ N}$$
$$F_{net} = 32 \text{ N}$$

Method 2:
Step 1. Calculate the net work done on the puck by calculating the change in kinetic energy.

$$W_{net} = \Delta E_k$$
$$= E_{kf} - E_{ki}$$
$$= 38.72 \text{ J} - 0 \text{ J}$$
$$W_{net} = 38.72 \text{ J}$$

Step 2. Use the net work formula to calculate the net force.

$$W_{net} = F_{net}\Delta d$$
$$F_{net} = \frac{W_{net}}{\Delta d}$$
$$= \frac{38.72 \text{ J}}{1.2 \text{ m}}$$
$$= 32.27 \text{ J/m}$$
$$F_{net} = 32 \text{ N}$$

Statement: Using two different methods, the average net force on the puck is 32 N.

3. Given: $m = 42$ kg; $v_i = 0$ m/s; $h_A = 16.0$ m; $h_D = 0$ m; $g = 9.8$ N/kg
Required: E_{gA}; h_B; h_C; E_{gD}
Analysis: $E_g = mgh$
(a) The gravitational potential energy of the person at position A:
Solution:

$$E_{gA} = mgh_A$$
$$= (42 \cancel{\text{kg}})\left(9.8 \frac{\text{N}}{\cancel{\text{kg}}}\right)(16.0 \text{ m})$$
$$= 6585.6 \text{ N}\bullet\text{m}$$
$$= 6585.6 \text{ J}$$
$$E_{gA} = 6.6 \text{ kJ}$$

Statement: The gravitational potential energy of the person at position A is 6.6 kJ.
(b) The height above the ground of the person at position B:
Given: $E_{gB} = 4500$ J
Solution:

$$E_{gB} = mgh_B$$
$$h_B = \frac{E_{gB}}{mg}$$
$$= \frac{4500 \text{ J}}{(42 \cancel{\text{kg}})\left(9.8 \frac{\text{N}}{\cancel{\text{kg}}}\right)}$$
$$= 10.93 \text{ J/N}$$
$$h_B = 11 \text{ m}$$

Statement: The height above the ground of the person at position B is 11 m.
(c) The height above the ground of the person at position C:
Given: $\Delta E_{g(\text{A to C})} = -4900$ J
Solution:
Step 1: Calculate the gravitational potential energy at position C.

$$\Delta E_{g(\text{A to C})} = E_{gC} - E_{gA}$$
$$E_{gC} = \Delta E_{g(\text{A to C})} + E_{gA}$$
$$= -4900 \text{ J} + 6585.6 \text{ J}$$
$$E_{gC} = 1685.6 \text{ J}$$

Step 2: Calculate the height at position C.

$$E_{gC} = mgh_C$$

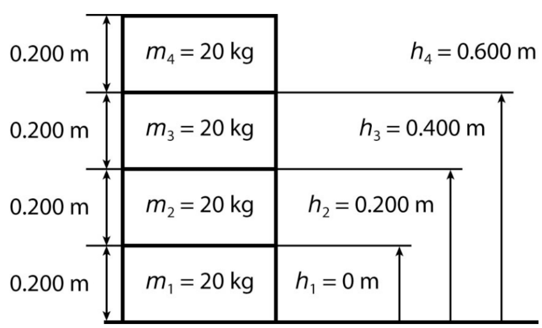
$$\begin{aligned}
h_C &= \frac{E_{gC}}{mg} \\
&= \frac{1685.6\ \text{J}}{(42\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)} \\
&= 4.09\ \text{J/N}
\end{aligned}$$

$$h_C = 4.1\ \text{m}$$

Statement: At position C, the person is 4.1 m high.

(d) The person's gravitational potential energy at ground level at D: The person is at the ground level, which has been used as the reference level for gravitational potential energy. Therefore, the person's height is 0 m. So the gravitational potential energy at position D is 0 J.

4. Given: $m_{\text{block}} = 2.0$ kg; $g = 9.8$ N/kg;
$h_{\text{block}} = 20.0$ cm $= 0.200$ m; One row has 10 blocks.
$m_{\text{row}} = 10 \times m_{\text{block}} = 10 \times 2.0\ \text{kg} = 20$ kg
There are 4 rows in total.
$m_1 = m_2 = m_3 = m_4 = m = 20$ kg; $h_{\text{row 1}} = 0$ m;
$h_{\text{row 2}} = 0.200$ m; $h_{\text{row 3}} = 0.400$ m; $h_{\text{row 4}} = 0.600$ m



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Required: E_{gT}

Analysis: $E_g = mgh$;
$E_{gT} = E_{\text{row 1}} + E_{\text{row 2}} + E_{\text{row 3}} + E_{\text{row 4}}$

Solution:

$$\begin{aligned}
E_{gT} &= E_{\text{row 1}} + E_{\text{row 2}} + E_{\text{row 3}} + E_{\text{row 4}} \\
&= m_1gh_1 + m_2gh_2 + m_3gh_3 + m_4gh_4 \\
&= (20\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(0.200\ \text{m} + 0.400\ \text{m} + 0.600\ \text{m}) \\
&= 235.2\ \text{N}\bullet\text{m} \\
&= 235.2\ \text{J}
\end{aligned}$$

$$E_{gT} = 240\ \text{J}$$

Statement: When the blocks are set in place, the gravitational potential energy stored in the wall is 240 J.

5. As the height of the basketball increases, its speed decreases, the kinetic energy decreases, and the gravitational potential energy increases. When the ball reaches its maximum height, it temporarily stops. Here, its gravitational potential energy is at the maximum and its kinetic energy is zero. As the ball begins to fall toward the ground, its speed increases so its kinetic energy increases, and its height decreases so its gravitational potential energy decreases. As it hits the floor, where the height is zero, the gravitational potential energy is zero and the speed and kinetic energy are at a maximum (and equal to its original value).

6. As the people in the drop tower ride are slowly pulled to the top,

- negative work is done on the people by gravity (acts in the direction opposite of motion)
- positive work is done on the people by the chains lifting the car (acts in the direction of motion)
- their gravitational potential energy increases because their height increases
- their kinetic energy remains constant if they are pulled up at a constant velocity

When the riders reach the top,

- their kinetic energy is zero because they are temporarily stopped
- their gravitational energy is at a maximum because they are at their highest point

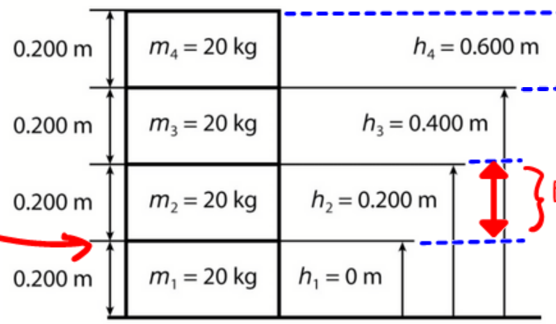
Immediately after the riders are released,

- there is positive work done on the people by gravity (acts in the direction of motion)
- their gravitational potential energy decreases because their height decreases
- their kinetic energy increases as they speed up on the way down

As the riders are safely slowed at the bottom by the braking system,

- there is positive work done on the people by gravity (acts in the direction of motion)
- there is negative work done on the people by the braking system (acts in the direction opposite of motion)
- their kinetic energy decreases as the braking system slows them down
- their gravitational potential energy decreases because their height decreases

4. Forty 2.0 kg blocks 20.0 cm thick are used to make a retaining wall in a backyard. Each row of the wall will contain 10 blocks. You may assume that the first block is placed at the reference level. How much gravitational potential energy is stored in the wall when the blocks are set in place? T/I



$Eg_2 = mgh$
$= (20)(9.8)(0.200)$
$= 39.2$

$Eg_3 = mgh$
$= (20)(9.8)(0.400)$
$= 78.4$

$Eg_4 = mgh$
$= (20)(9.8)(0.600)$
$= 117.6$

$Eg_{Total} = Eg_2 + Eg_3 + Eg_4$
$= 39.2 + 78.4 + 117.6$

$\boxed{Eg_{total} = 235.2 \text{ J}}$

Each block has a separate gravitational potential energy. Since the first block does not move, no energy is expended, hence this is the reference level. The 2nd block is lifted 0.200 m, the 3rd block is lifted 2 x 0.200m, and the 4th block is lifted 3 x 0.200m. The gravitational potential energy of the stack is the sum of the gravitational potential energies for the individual blocks.