Section 3.3: Newton's Second Law of Motion

Tutorial 1 Practice, page 133

1. Given: \( \vec{F}_{\text{net}} = 126 \, \text{N} \, [\text{S}] \); \( m = 70 \, \text{kg} \)
   Required: \( \vec{a} \)
   Analysis: \( \vec{F}_{\text{net}} = m \vec{a} \). Choose north as positive. So, south is negative.
   Solution:
   \[
   \vec{F}_{\text{net}} = m \vec{a} \\
   \vec{a} = \frac{\vec{F}_{\text{net}}}{m} \\
   a = \frac{126 \, \text{N}}{70 \, \text{kg}} \\
   = 1.8 \, \text{m/s}^2 \\
   \vec{a} = 1.8 \, \text{m/s}^2 \, [\text{S}] 
   \]
   Statement: The acceleration of the sprinter is \( 1.8 \, \text{m/s}^2 \) [S].

2. Given: \( \vec{a} = 1.20 \, \text{m/s}^2 \, [\text{forward}] \); \( \vec{F}_{\text{net}} = 1560 \, \text{N} \) [forward]
   Required: \( m \)
   Analysis: \( \vec{F}_{\text{net}} = m \vec{a} \). Choose forward as positive.
   Solution:
   \[
   \vec{F}_{\text{net}} = m \vec{a} \\
   m = \frac{\vec{F}_{\text{net}}}{\vec{a}} \\
   = \frac{1560 \, \text{N}}{1.20 \, \text{m/s}^2} \\
   = 1300 \, \text{kg} 
   \]
   Statement: The mass of the car is 1300 kg.

3. Given: \( \vec{v}_1 = 6.0 \, \text{m/s} \, [\text{E}] \); \( \vec{v}_2 = 14.0 \, \text{m/s} \, [\text{E}] \);
   \( \Delta t = 6.0 \, \text{s} \); \( m = 58 \, \text{kg} \)
   Required: \( \vec{F}_{\text{net}} \)
   Analysis: Choose east as positive. First calculate the acceleration using \( \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \). Then calculate the net force using \( \vec{F}_{\text{net}} = m \vec{a} \).
   Solution:
   \[
   a = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \\
   = \frac{14.0 \, \text{m/s} - (6.0 \, \text{m/s})}{6.0 \, \text{s}} \\
   a = +1.33 \, \text{m/s}^2 \, \text{ (one extra digit carried)} 
   \]
   Calculate the net force.

Copyright © 2011 Nelson Education Ltd.
Solution: 
\[ F_{net} = -24 \text{ N} + (-31 \text{ N}) + 19 \text{ N} \]
\[ = -36 \text{ N} \]
\[ \vec{F}_{net} = 36 \text{ N} \quad \text{[left]} \]
Calculate the acceleration.
\[ \vec{F}_{net} = m \vec{a} \]
\[ a = \frac{\vec{F}_{net}}{m} \]
\[ a = \frac{-36 \text{ N}}{8.0 \text{ kg}} \]
\[ = -4.5 \text{ m/s}^2 \]
\[ \vec{a} = 4.5 \text{ m/s}^2 \quad \text{[left]} \]
**Statement:** The net force applied to the object is 36 N [left] and its acceleration is 4.5 m/s² [left].

(b) Given: \( m = 125 \text{ kg} \); three vertical forces of 1200 N [up], 1100 N [up], and 1300 N [down]; two horizontal forces of 600 N [right] and 600 N [left]

**Required:** \( \vec{F}_{net} \); \( \vec{a} \)

**Analysis:** The left and right forces cancel each other. Find \( \vec{F}_{net} \) by adding all vertical forces. Choose up as positive. So, down is negative. Calculate the acceleration using \( \vec{F}_{net} = m \vec{a} \).

**Solution:**
\[ F_{net} = +1200 \text{ N} + 1100 \text{ N} + (-1300 \text{ N}) \]
\[ = +1000 \text{ N} \]
\[ \vec{F}_{net} = 1000 \text{ N} \quad \text{[up]} \]

Calculate the acceleration.
\[ \vec{F}_{net} = m \vec{a} \]
\[ a = \frac{\vec{F}_{net}}{m} \]
\[ a = \frac{+1000 \text{ N}}{125 \text{ kg}} \]
\[ = +8 \text{ m/s}^2 \]
\[ \vec{a} = 8 \text{ m/s}^2 \quad \text{[up]} \]
**Statement:** The net force applied to the object is 1000 N [up] and its acceleration is 8 m/s² [up].

6. Given: \( \vec{F}_1 = 310 \text{ N} \quad \text{[forward]} \); \( \vec{F}_2 = 354 \text{ N} \quad \text{[forward]} \); \( \vec{F}_3 = 40 \text{ N} \quad \text{[backward]} \); \( m = 390 \text{ kg} \)

**Required:** \( \vec{a} \)

**Analysis:** Find \( \vec{F}_{net} \) by adding all forward and backward forces. Choose forward as positive. So, backward is negative. Calculate the acceleration using \( \vec{F}_{net} = m \vec{a} \).

**Solution:**
\[ F_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 \]
\[ F_{net} = +310 \text{ N} + 354 \text{ N} + (-40 \text{ N}) \]
\[ = +624 \text{ N} \]
\[ \vec{F}_{net} = 624 \text{ N} \quad \text{[forward]} \]
Calculate the acceleration.
\[ \vec{F}_{net} = m \vec{a} \]
\[ a = \frac{\vec{F}_{net}}{m} \]
\[ a = \frac{+624 \text{ N}}{390 \text{ kg}} \]
\[ = +1.6 \text{ m/s}^2 \]
\[ \vec{a} = 1.6 \text{ m/s}^2 \quad \text{[forward]} \]
**Statement:** The acceleration of the bobsled is 1.6 m/s² [forward].

**Tutorial 2 Practice, page 135**

1. (a) Given: \( m_1 = 1.20 \text{ kg} \); \( m_2 = 0.60 \text{ kg} \); \( \vec{F}_1 = 0 \text{ N} \)

**Required:** \( \vec{a} \)

**Analysis:** Draw a FBD of each object.

For the cart, the normal force and gravity cancel each other.
So, \( (F_{net})_{cart} = F_T = m_1 \vec{a} \).
\[ m_1 \vec{a} = F_T \] (Equation 1)

For the hanging object,
\[ (F_{net})_{object} = F_{g1} - F_T = m_2 \vec{a} \]
\[ m_2 \vec{a} = m_2 g - F_T \] (Equation 2)

The cart will accelerate to the right. Choose right as positive. So, left is negative. Solve the two equations for \( \vec{a} \).

**Solution:**

\[ F_{net} = \vec{F}_N \quad \text{FBD of cart} \]
\[ \vec{F}_N \]
\[ m_1 \]
\[ F_{g1} \]
\[ \vec{F}_T \]
\[ m_2 \]
\[ F_{g2} \]

Add the equations to solve for \( \vec{a} \).
\[ m_1a + m_2a = F_T + m_2g - F_T \]
\[ m_1a + m_2a = m_2g \]
\[ (m_1 + m_2)a = m_2g \]
(1.20 kg + 0.60 kg)a = (0.60 kg)(9.8 m/s²) 
\[ a = 3.3 \text{ m/s}^2 \]
The acceleration of the cart is 3.3 m/s² [right].

(b) Given: \( m_1 = 1.20 \text{ kg}; m_2 = 0.60 \text{ kg}; \) 
\( F_T = 0.50 \text{ N} \) [left]

Required: \( \ddot{a} \)

Analysis: Draw a FBD of each object.

For the cart, the normal force and gravity cancel each other.
So, \( (F_{\text{net}})_{\text{cart}} = F_T - F_N = m_1a \).
\[ m_1a = F_T - F_N \] (Equation 1)

For the hanging object,
\[ (F_{\text{net}})_{\text{object}} = F_{g_2} - F_T = m_2a \].
\[ m_2a = m_2g - F_T \] (Equation 2)

The cart will accelerate to the right. Choose right as positive. So, left is negative. Solve the two equations for \( a \).

Solution:
For the cart, the normal force and gravity cancel each other.
\[ m_1a = F_T - F_N \] (Equation 1)

For the hanging object,
\[ (F_{\text{net}})_{\text{object}} = F_{g_2} - F_T = m_2a \].
\[ m_2a = m_2g - F_T \] (Equation 2)

The acceleration of the cart is 3.3 m/s² [right].

(b) If the mass of the object on top of the cart increases, the acceleration of the cart decreases. Using the equation for the acceleration of the cart,
\[ a = \frac{m_2g}{m_1 + m_2} \], the value \( a \) decreases when the value \( m_1 \) increases.

(c) If an object is taken from the top of the cart and tied to the hanging object, the acceleration of the cart increases. Using the equation for the acceleration of the cart,
\[ a = \frac{m_2g}{m_1 + m_2} \], the value \( a \) increases when the value \( m_1 \) decreases and the value \( m_2 \) increases.

Section 3.3 Questions, page 136

1. (a) Given: \( m = 72 \text{ kg}; \ddot{a} = 1.6 \text{ m/s}^2 \) [forward]

Required: \( F_{\text{net}} \)

Analysis: \( F_{\text{net}} = m\ddot{a} \). Choose forward as positive.

Solution:

Chapter 3: Newton’s Laws of Motion 3.3-3
$F_{\text{net}} = m\ddot{a}$
$F_{\text{net}} = (72 \text{ kg})(+1.6 \text{ m/s}^2)$
$= +120 \text{ N}$
$F_{\text{net}} = 120 \text{ N} \ [\text{forward}]$

**Statement:** The net force on the rugby player is $120 \text{ N} \ [\text{forward}].$

**(b) Given:** $m = 2.3 \text{ kg}; \ddot{a} = 12 \text{ m/s}^2 \ [\text{up}]$

**Required:** $F_{\text{net}}$

**Analysis:** $F_{\text{net}} = m\ddot{a} \ . \ Choose \ up \ as \ positive.$

**Solution:**
$F_{\text{net}} = m\ddot{a}$
$= (2.3 \text{ kg})(+12 \text{ m/s}^2)$
$= +28 \text{ N}$
$F_{\text{net}} = 28 \text{ N} \ [\text{up}]$

**Statement:** The net force on the model rocket is $28 \text{ N} \ [\text{up}].$

2. *(a) Given:* $F_{\text{net}} = 2.4 \times 10^4 \text{ N} \ [\text{E}]; m = 5.0 \text{ kg}$

**Required:** $\ddot{a}$

**Analysis:** $F_{\text{net}} = m\ddot{a} \ . \ Choose \ east \ as \ positive. \ So, \ west \ is \ negative.$

**Solution:**
$F_{\text{net}} = m\ddot{a}$
$\ddot{a} = \frac{F_{\text{net}}}{m}$
$a = \frac{+2.4 \times 10^4 \text{ N}}{5.0 \text{ kg}}$
$= +4800 \text{ m/s}^2$
$\ddot{a} = +4800 \text{ m/s}^2 \ [\text{E}]$

**Statement:** The acceleration of the shell is $4800 \text{ m/s}^2 \ [\text{E}].$

**(b) Given:** $m = 160 \text{ g}; F_{\text{net}} = 24 \text{ N} \ [\text{forward}]$

**Required:** $\ddot{a}$

**Analysis:** $F_{\text{net}} = m\ddot{a} \ ; \ First \ calculate \ the \ value \ m \ to \ SI \ units. \ Choose \ forward \ as \ positive.$

**Solution:**
$m = 160 = 0.16 \text{ kg}$

$F_{\text{net}} = m\ddot{a}$
$\ddot{a} = \frac{F_{\text{net}}}{m}$
$a = \frac{+24 \text{ N}}{0.16 \text{ kg}}$
$= +150 \text{ m/s}^2$
$\ddot{a} = +150 \text{ m/s}^2 \ [\text{forward}]$

**Statement:** The acceleration of the hockey puck is $150 \text{ m/s}^2 \ [\text{forward}].$

3. *(a) Given:* $\ddot{a} = 1.2 \text{ m/s}^2 \ [\text{backward}];$

$F_{\text{net}} = 1400 \text{ N} \ [\text{backward}]$

**Required:** $m$

**Analysis:** $F_{\text{net}} = m\ddot{a} \ . \ Choose \ forward \ as \ positive.$

**Solution:**
$m = \frac{F_{\text{net}}}{\ddot{a}}$
$= \frac{1400 \text{ N}}{-1.2 \text{ m/s}^2}$
$m = 1200 \text{ kg}$

**Statement:** The mass of the car is $1200 \text{ kg}.$

**(b) Given:** $F_{\text{net}} = 33 \text{ N} \ [\text{forward}];$

$\ddot{a} = 6.0 \text{ m/s}^2 \ [\text{forward}]$

**Required:** $m$

**Analysis:** $F_{\text{net}} = m\ddot{a} \ . \ Choose \ forward \ as \ positive.$

**Solution:**
$m = \frac{F_{\text{net}}}{\ddot{a}}$
$= \frac{+33 \text{ N}}{+6.0 \text{ m/s}^2}$
$m = 5.5 \text{ kg}$

**Statement:** The mass of the shot put is $5.5 \text{ kg}.$

4. **Given:** $m = 54 \text{ kg}; \ v_1 = 0 \text{ m/s};$

$\ddot{v}_2 = 12 \text{ m/s} \ [\text{downhill}]; \Delta t = 5.0 \text{ s}$

**Required:** $F_{\text{net}}$

**Analysis:** $F_{\text{net}} = m\ddot{a} \ ; \ First \ calculate \ the \ acceleration \ using \ \ddot{a} = \frac{\ddot{v}_2 - \dot{v}_1}{\Delta t} \ . \ Choose \ uphill \ as \ positive. \ So, \ downhill \ is \ negative.$

**Solution:**
Since $\dot{v}_1 = 0 \text{ m/s},$

$a = \frac{\ddot{v}_2}{\Delta t}$
$= \frac{-12 \text{ m/s}}{5.0 \text{ s}}$
$a = -2.4 \text{ m/s}^2$
$\ddot{a} = 2.4 \text{ m/s}^2 \ [\text{downhill}]$
Calculate the net force.

\[ F_{\text{net}} = m \ddot{a} \]

\[ F_{\text{net}} = (54 \text{ kg})(-2.4 \text{ m/s}^2) = -130 \text{ N} \]

\[ F_{\text{net}} = 130 \text{ N} \text{ [downhill]} \]

**Statement:** The net force acting on the skier is 130 N [downhill].

5. **Given:** \( v_1 = 0 \text{ m/s}; F_{\text{net}} = 1.2 \text{ N [forward]} \);
\( \Delta \ddot{a} = 6.6 \text{ m [forward]} \); \( v_2 = 3.2 \text{ m/s [forward]} \)

**Required:** \( m \)

**Analysis:** \( F_{\text{net}} = m \ddot{a} \); \( \ddot{v}_2 = \ddot{v}_1 + 2a \Delta \ddot{a} \). Choose forward as positive. First calculate the acceleration using \( \ddot{v}_2 = \ddot{v}_1 + 2a \Delta \ddot{a} \).

**Solution:**
Since \( v_1 = 0 \text{ m/s}, \)
\[ v_2^2 = 2a \Delta \ddot{a} \]
\[ a = \frac{v_2^2}{2 \Delta \ddot{a}} = \frac{(+3.2 \text{ m/s})^2}{2(+6.6 \text{ m})} \]
\[ a = +0.776 \text{ m/s}^2 \] (one extra digit carried)

Calculate the mass.

\[ F_{\text{net}} = m \ddot{a} \]
\[ m = \frac{F_{\text{net}}}{a} = \frac{+1.2 \text{ N}}{+0.776 \text{ m/s}^2} \]
\[ m = 1.5 \text{ kg} \]

**Statement:** The mass of the cart is 1.5 kg.

6. (a) **Given:** \( m = 58 \text{ kg}; F_{\text{net}} = 720 \text{ N [up]} \)

**Required:** \( m \)

**Analysis:** Add all the vertical forces. Use \( F_{\text{net}} = F_k + F_g \). Choose up as positive.

**Solution:**
\[ F_{\text{net}} = F_k + F_g \]
\[ F_{\text{net}} = 58 \text{ kg}(9.8 \text{ m/s}^2) \]
\[ = +580 \text{ N} \]
\[ F_{\text{net}} = 180 \text{ N [up]} \]

**Statement:** The net force acting on the person is 150 N [up].

(b) **Given:** \( m = 58 \text{ kg}; F_{\text{net}} = 150 \text{ N [up]} \)

**Required:** \( \ddot{a} \)

Analysis: \( F_{\text{net}} = m \ddot{a} \). Choose up as positive.

**Solution:**
\[ F_{\text{net}} = m \ddot{a} \]
\[ \ddot{a} = \frac{F_{\text{net}}}{m} = \frac{+150 \text{ N}}{58 \text{ kg}} \]
\[ = +2.6 \text{ m/s}^2 \]

**Statement:** The acceleration of the person is 2.6 m/s^2 [up].

7. **Given:** \( F_{\text{net}} = 36 \text{ N [forward]} \);
\( a_1 = 6.0 \text{ m/s}^2 \text{ [forward]} \); \( a_{1+2} = 2.0 \text{ m/s}^2 \text{ [forward]} \)

**Required:** \( a_2 \)

**Analysis:** \( F_{\text{net}} = m \ddot{a} \). Choose forward as positive.

**Solution:**
For mass \( m_1 \),
\[ F_{\text{net}} = m_1 \ddot{a}_1 \]
\[ m_1 = \frac{F_{\text{net}}}{a_1} = \frac{36 \text{ N}}{6.0 \text{ m/s}^2} \]
\[ m_1 = 6.0 \text{ kg} \]

For masses \( m_1 \) and \( m_2 \) together,
\[ F_{\text{net}} = (m_1 + m_2) \ddot{a}_{1+2} \]
\[ m_1 + m_2 = \frac{F_{\text{net}}}{a_{1+2}} \]
\[ m_2 = \frac{F_{\text{net}}}{a_{1+2}} - m_1 \]
\[ = \frac{36 \text{ N}}{2.0 \text{ m/s}^2} - 6.0 \text{ kg} \]
\[ m_2 = 12 \text{ kg} \]

For mass \( m_2 \),
\[ F_{\text{net}} = m_2 \ddot{a}_2 \]
\[ \ddot{a}_2 = \frac{F_{\text{net}}}{m_2} \]
\[ = \frac{36 \text{ N}}{12 \text{ kg}} \]
\[ = 3.0 \text{ m/s}^2 \]

**Statement:** Mass \( m_2 \) will experience an acceleration of 3.0 m/s^2.
8. (a) Choose up and east as positive. So, down and west is negative.

(b) Given: \( m = 1300 \text{ kg}; \ a = 1.6 \text{ m/s}^2 \) [E]; \( \vec{F}_t = -3800 \text{ N} \) [W]

Required: \( \vec{F}_k \)

Analysis: The normal force and gravity cancel each other since the car is on horizontal ground. To find \( \vec{F}_k \), add all the horizontal forces. Use \( \vec{F}_{\text{net}} = ma \) and \( \vec{F}_{\text{net}} = \vec{F}_k + \vec{F}_t \).

Solution:
\[
\vec{F}_{\text{net}} = \vec{F}_k + \vec{F}_t
\]
\[
\vec{F}_k = \vec{F}_{\text{net}} - \vec{F}_t
\]
\[
F_k = ma - F_t
\]
\[
= (1300 \text{ kg})(+1.6 \text{ m/s}^2) - (-3800 \text{ N})
\]
\[
= +5900 \text{ N}
\]
\( \vec{F}_k = 5900 \text{ N} \) [E]

Statement: The applied force acting on the car is 5900 N [E].

9. Assume that no friction acts on the chain on top of the table.

\( m_1 \) = mass of chain on top of table

\( m_2 \) = mass of chain hanging over the edge

The tension, \( F_T \), in the chain is the same for both \( m_1 \) and \( m_2 \).

(a) For the chain on top of the table, the normal force and gravity cancel each other.

\( F_{\text{net}} = F_T = m_1 a \) (Equation 1)

For the hanging chain,

\( F_{\text{net}} = F_g - F_T = m_2 a \) (Equation 2)

Add the equations.

\( m_1 a + m_2 a = F_T + m_2 g - F_T \)

\( (m_1 + m_2) a = m_2 g \)

The chain will accelerate to the right down the table. The force of gravity acting on the hanging chain, \( m_2 g \), causes the acceleration.

(b) Solve the equations for \( a \).

\( (m_1 + m_2) a = m_2 g \)

\[ a = \frac{m_2 g}{m_1 + m_2} \]

From the equation, when the value \( m_2 \) increases, the value \( (m_1 + m_2) \) stays the same, and the value \( a \) increases. As more chain moves over the edge of the table, the acceleration of the chain increases.

10. (a) Given: \( m = 80 \text{ kg}; \) three horizontal forces of \( 170 \text{ N} \) [left], \( 170 \text{ N} \) [left], and \( 150 \text{ N} \) [right]

Required: \( a \)

Analysis: The normal force and gravity cancel each other since the crate is on the floor. Find \( \vec{F}_{\text{net}} \) by adding all horizontal forces. Choose right as positive. So, left is negative. Calculate the acceleration using \( \vec{F}_{\text{net}} = ma \).

Solution:

\( F_{\text{net}} = -170 \text{ N} + (-170 \text{ N}) + 150 \text{ N} \)

\( = -190 \text{ N} \)

\( \vec{F}_{\text{net}} = 190 \text{ N} \) [left]

Calculate the acceleration.

\( \vec{F}_{\text{net}} = ma \)

\[ a = \frac{\vec{F}_{\text{net}}}{m} \]

\[ a = \frac{-190 \text{ N}}{80 \text{ kg}} \]

\[ = -2.4 \text{ m/s}^2 \]

\( a = 2.4 \text{ m/s}^2 \) [left]

Statement: The acceleration of the crate is 2.4 m/s² [left].

(b) If a fourth student jumps on top of the crate, the mass, \( m \), of the crate increases but the net force \( \vec{F}_{\text{net}} \) on the crate is the same. Using \( \vec{F}_{\text{net}} = ma \), as the value \( m \) increases, the value \( a \) decreases. So, the magnitude of the acceleration of the crate decreases.

11. Given: \( m = 30 \text{ kg}; \ v_i = 0 \text{ m/s}; \Delta t = 22 \text{ m} \)

\( m_{\text{max}} = 12 \text{ kg} \)

Required: \( \Delta t \)

Analysis: Use the equation \( F_T = m_a \) to find the maximum tension of the string when it holds up a 12 kg mass. Assume no friction on the ice. The normal force and gravity cancel each other since the object is on the ice. The net force acting on the pulled object is the tension in the string. Use \( F_T = ma \) to calculate the acceleration and use...
\[ \Delta d = v_i \Delta t + \frac{1}{2} a \Delta t^2 \] to calculate the minimum possible time.

**Solution:**

\[ F_T = m g \]
\[ = (12 \text{ kg})(9.8 \text{ m/s}) \]
\[ F_T = 117.6 \text{ N} \]

Calculate the acceleration.

\[ F_T = ma \]
\[ a = \frac{F_T}{m} \]
\[ = \frac{117.6 \text{ N}}{30 \text{ kg}} \]
\[ a = 3.92 \text{ m/s}^2 \]

Calculate the minimum possible time.

Since \( v_i = 0 \text{ m/s} \),

\[ \Delta t = \frac{2 \Delta d}{a} \]
\[ \Delta t = \frac{2(22 \text{ m})}{3.92 \text{ m/s}^2} \]
\[ \Delta t = 3.4 \text{ s} \]

**Statement:** The minimum possible time to complete the task is 3.4 s.

### Table 12

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>Friction (N) [W]</th>
<th>Applied force (N) [E]</th>
<th>Net force (N) [E]</th>
<th>Acceleration (m/s^2) [E]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>9.0</td>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4.0</td>
<td>9.0</td>
<td>13.0</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>4.0</td>
<td>9.0</td>
<td>17.4</td>
<td>8.4</td>
<td>2.1</td>
</tr>
<tr>
<td>4.0</td>
<td>9.0</td>
<td>23.0</td>
<td>14.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

(b) The \( y \)-intercept represents the friction. When the applied force equals the friction, the net force on the object is zero and its acceleration will also be zero.

The slope represents the mass of the object, which is 4.0 kg.