Section 2.1: Forces and Free-Body Diagrams
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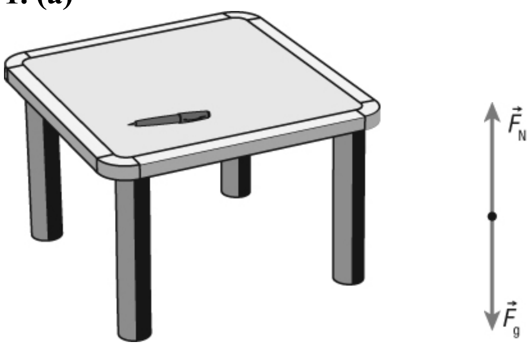
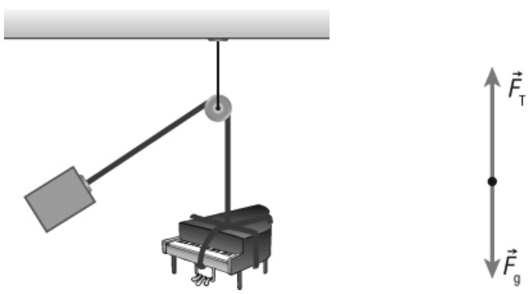
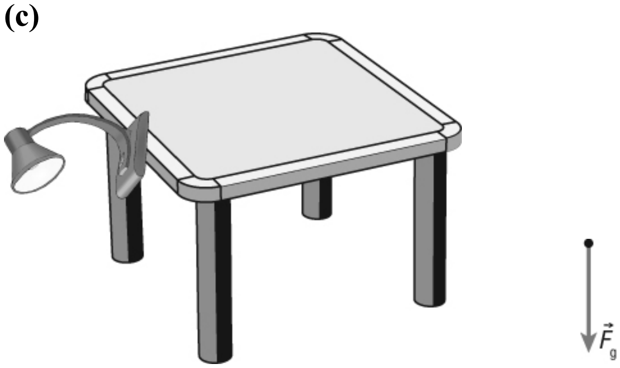
1. (a)



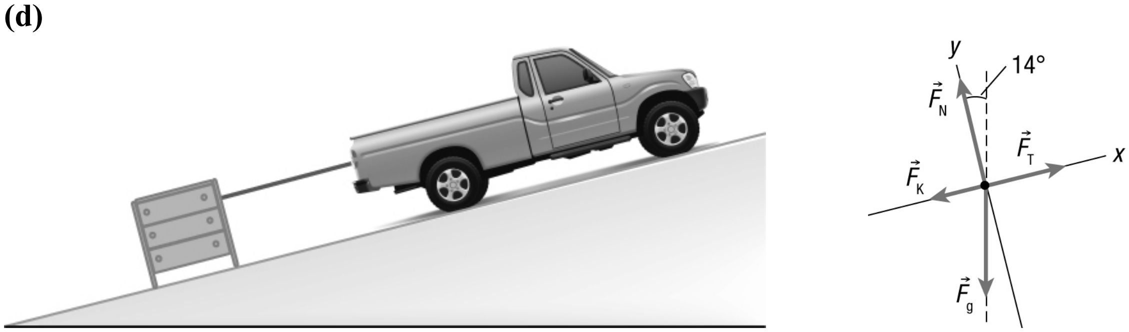
(b)



(c)



(d)



2. While the ball is in the air (from just after it leaves your hand, until just before it makes contact with the object that it will hit), it is only acted upon by one force—the force of gravity, $\vec{F}_g$. Therefore, for (a), (b), and (c), the FBD of the force acting on the ball is shown below.

3.

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1. (a) Given: $\vec{F}_a = 25$ N [forward 40.0° up]; $\vec{F}_g = 4.2$ N [down]

Required: $\Sigma\vec{F}$

Analysis: $\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $\theta = \tan^{-1}\left(\dfrac{\Sigma F_y}{\Sigma F_x}\right)$. Choose forward and up as positive.

Solution: For the x-component of the force,

$$\begin{aligned}\vec{F}_{ax} &= \vec{F}\cos\theta \\ &= (25\text{ N})\cos 40.0° \\ \vec{F}_{ax} &= 19.15\text{ N (two extra digits carried)}\end{aligned}$$

$$\begin{aligned}\Sigma\vec{F}_x &= \vec{F}_{ax} + \vec{F}_{gx} \\ &= 19.15\text{ N} + 0.0\text{N} \\ \Sigma\vec{F}_x &= 19.15\text{ N (two extra digits carried)}\end{aligned}$$

For the y-component of the force,

$$\begin{aligned}\vec{F}_{ay} &= \vec{F}\sin\theta \\ &= (25\text{ N})\sin 40.0° \\ \vec{F}_{ay} &= 16.07\text{ N (two extra digits carried)}\end{aligned}$$

$$\Sigma\vec{F}_y = \vec{F}_{ay} + (-\vec{F}_{gy})$$
$$= 16.07 - 4.2 \text{ N}$$
$$\Sigma\vec{F}_y = 11.87 \text{ N (two extra digits carried)}$$

Construct $\Sigma\vec{F}$:

$$\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$$
$$= \sqrt{(19.15 \text{ N})^2 + (11.87 \text{ N})^2}$$
$$= 22.53 \text{ N}$$
$$\left|\Sigma\vec{F}\right| = 23 \text{ N}$$

$$\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$$
$$= \tan^{-1}\left(\frac{11.87 \cancel{\text{ N}}}{19.15 \cancel{\text{ N}}}\right)$$
$$\theta = 32°$$

Statement: The net force acting on the soccer ball is 23 N [32° above the horizontal].

(b) Given: $\vec{F}_1 = 15$ N [N 35° E]**;** $\vec{F}_2 = 25$ N [N 54° W]

Required: $\Sigma\vec{F}$

Analysis: $\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$. Choose east and north as positive.

Solution: For the *x*-component of the force,

$$\vec{F}_{1x} = \vec{F}\cos\theta$$
$$= (15 \text{ N})\cos 35°$$
$$\vec{F}_{1x} = 12.29 \text{ N (two extra digits carried)}$$

$$\vec{F}_{2x} = \vec{F}\cos\theta$$
$$= (25 \text{ N})\cos 54°$$
$$\vec{F}_{2x} = 14.70 \text{ N (two extra digits carried)}$$

$$\Sigma\vec{F}_x = \vec{F}_{1x} + \vec{F}_{2x}$$
$$= 12.29 \text{ N} + 14.70 \text{ N}$$
$$\Sigma\vec{F}_x = 26.99 \text{ N (two extra digits carried)}$$

For the y-component of the force,

$$\begin{aligned}\vec{F}_{1y} &= \vec{F}\sin\theta \\ &= (15\text{ N})\sin 35° \\ \vec{F}_{1y} &= 8.604\text{ N (two extra digits carried)}\end{aligned}$$

$$\begin{aligned}\vec{F}_{2y} &= \vec{F}\sin\theta \\ &= (-25\text{ N})\sin 54° \\ \vec{F}_{2y} &= -20.22\text{ N (two extra digits carried)}\end{aligned}$$

$$\begin{aligned}\Sigma\vec{F}_{y} &= \vec{F}_{1y} + \vec{F}_{2y} \\ &= 8.604 - 20.22 \\ \Sigma\vec{F}_{y} &= -11.62\text{ N (two extra digits carried)}\end{aligned}$$

Construct $\Sigma\vec{F}$:

$$\begin{aligned}\left|\Sigma\vec{F}\right| &= \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2} \\ &= \sqrt{(26.99\text{ N})^2 + (-11.62\text{ N})^2} \\ &= 29.39\text{ N} \\ \left|\Sigma\vec{F}\right| &= 29\text{ N}\end{aligned}$$

$$\begin{aligned}\theta &= \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right) \\ &= \tan^{-1}\left(\frac{-11.62\ \cancel{\text{N}}}{26.99\ \cancel{\text{N}}}\right) \\ \theta &= 23°\end{aligned}$$

Statement: The net force acting on the sled is 29 N [N 23° W].

(c) Given: $\vec{F}_{\text{g}} = 4.4\times10^2$ N [down]; $\vec{F}_1 = 4.3\times10^2$ N [up 35° left]; $\vec{F}_2 = 2.8\times10^2$ N [up]

Required: $\Sigma\vec{F}$

Analysis: $\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$. Choose right and up as positive.

Solution: For the x-component of the force,

$$\begin{aligned}\Sigma\vec{F}_{x} &= \vec{F}_{\text{g}x} + \vec{F}_{1x} + \vec{F}_{2x} \\ &= (0\text{ N}) + (-430\text{ N})\sin 35° + (0\text{ N}) \\ \Sigma\vec{F}_{x} &= -246.6\text{ N (two extra digits carried)}\end{aligned}$$

For the *y*-component of the force,

$$\begin{aligned}\Sigma\vec{F}_y &= \vec{F}_{gy} + \vec{F}_{1y} + \vec{F}_{2y}\\ &= (-440\text{ N}) + (430\text{ N})\cos 35° + (280\text{ N})\\ &= -440\text{ N} + 352.2\text{ N} + 280\text{ N}\\ \Sigma\vec{F}_y &= 192.2\text{ N (two extra digits carried)}\end{aligned}$$

Construct $\Sigma\vec{F}$:

$$\begin{aligned}\left|\Sigma\vec{F}\right| &= \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}\\ &= \sqrt{(246.6\text{ N})^2 + (192.2\text{ N})^2}\\ &= 310\text{ N}\\ \left|\Sigma\vec{F}\right| &= 3.1\times10^2\text{ N}\end{aligned}$$

$$\begin{aligned}\theta &= \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)\\ &= \tan^{-1}\left(\frac{192.24\ \cancel{\text{N}}}{246.64\text{ N}}\right)\\ \theta &= 38°\end{aligned}$$

Statement: The net force acting on the performer is 3.1×10^2 N [up 38° left] or [left 52° up].

2. (a) Given: $\vec{F}_1 = 1.2\times10^4$ N [E 12° N]; $\vec{F}_2 = 1.2\times10^4$ N [E 12° S]; $\Sigma\vec{F} = 0$ N

Required: $\vec{F}_\text{f}$

Analysis: $\Sigma\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_\text{f}$. Choose east and north as positive.

Solution: $\Sigma\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_\text{f}$

$$\begin{aligned}0 &= \vec{F}_1 + \vec{F}_2 + \vec{F}_\text{f}\\ \vec{F}_\text{f} &= -\vec{F}_1 - \vec{F}_2\end{aligned}$$

$$\begin{aligned}\vec{F}_{\text{f}x} &= -\vec{F}_{1x} - \vec{F}_{2x}\\ &= -(1.2\times10^4\text{ N})\cos 12° - (1.2\times10^4\text{ N})\cos 12°\\ \vec{F}_{\text{f}x} &= -2.3\times10^4\text{ N}\end{aligned}$$

Statement: The force of friction on the rock is 2.3×10^4 N [W].

(b) Answers may vary. Sample answer: I notice that the forces of the tractors are equal in magnitude but act in directions symmetric about the east. So the net force of the tractors has to be due east, making the force of friction due west. Another way to say this is that the north component of one tractor force cancels the south component of the other.

3. Given: $m_1 = 15.0$ kg; $m_2 = 7.0$ kg; $m_3 = 13.0$ kg; $g = 9.8$ m/s^2

Required: $\vec{F}_{\text{T}1}$; $\vec{F}_{\text{T}2}$; $\vec{F}_{\text{T}3}$

Analysis: Draw an FBD for each mass. Choose up as positive.

Solution: The FBDs are shown below.

Mass 1 ($m_1 = 15.0$ kg)

$$\Sigma\vec{F}_y = \vec{F}_{T1y} + \vec{F}_{T2y} + \vec{F}_{gy}$$
$$0 \text{ N} = \vec{F}_{T1} - \vec{F}_{T2} - (15.0 \text{ kg})g$$
$$\vec{F}_{T1} - \vec{F}_{T2} = (15.0 \text{ kg})g \quad \text{(Equation 1)}$$

Mass 2 ($m_2 = 7.0$ kg)

$$\Sigma\vec{F}_y = \vec{F}_{T2y} + \vec{F}_{T3y} + \vec{F}_{gy}$$
$$0 \text{ N} = \vec{F}_{T2} - \vec{F}_{T3} - (7.0 \text{ kg})g$$
$$\vec{F}_{T2} - \vec{F}_{T3} = (7.0 \text{ kg})g \quad \text{(Equation 2)}$$

Mass 3 ($m_3 = 13.0$ kg)

$$\Sigma\vec{F}_y = \vec{F}_{3y} + \vec{F}_{gy}$$
$$0 \text{ N} = \vec{F}_{T3} - (13.0 \text{ kg})g$$
$$\vec{F}_{T3} = (13.0 \text{ kg})g \text{ (Equation 3)}$$

Solve for the tensions in the wires, working from equation (3) to equation (2) to equation (1):

$$\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma\vec{F}_x)^2 + (\Sigma\vec{F}_y)^2}$$
$$= \sqrt{(0.3392\text{ N})^2 + (1.2880\text{ N})^2}$$
$$\left|\Sigma\vec{F}\right| = 1.3\text{ N}$$

$$\vec{F}_{\text{T3}} = (13.0\text{ kg})g \quad \text{(Equation 1)}$$
$$\vec{F}_{\text{T3}} = 1.3\times 10^2\text{ N}$$

$$\vec{F}_{\text{T2}} - \vec{F}_{\text{T3}} = (7.0\text{ kg})g \quad \text{(Equation 2)}$$
$$\vec{F}_{\text{T2}} = \vec{F}_{\text{T3}} + (7.0\text{ kg})g$$
$$= (13.0\text{ kg})g + (7.0\text{ kg})g$$
$$\vec{F}_2 = 2.0\times 10^2\text{ N}$$

$$\vec{F}_{\text{T1}} - \vec{F}_{\text{T2}} = (15.0\text{ kg})g \quad \text{(Equation 3)}$$
$$\vec{F}_{\text{T1}} = \vec{F}_{\text{T2}} + (15.0\text{ kg})g$$
$$= (13.0\text{ kg})g + (7.0\text{ kg})g + (15.0\text{ kg})g$$
$$\vec{F}_{\text{T1}} = 3.4\times 10^2\text{ N}$$

Statement: The tension in the top wire is $3.4\times 10^2\text{ N}$, in the middle wire it is 2.0×10^2 N, and in the bottom wire it is 1.3×10^2 N.

4. Given: $\vec{F}_{\text{air}} = 0.40$ N [32° above the horizontal]; $\vec{F}_{\text{g}} = 1.5$ N [down]

Required: $\Sigma\vec{F}$

Analysis: $\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $\theta = \tan^{-1}\left(\dfrac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$; use forward and up as positive.

Solution: For the x-component of the force,

$$\Sigma\vec{F}_x = \vec{F}_{\text{air}x} + \vec{F}_{\text{g}x}$$
$$= (-0.40\text{ N})\cos 32° + (0\text{ N})$$
$$\Sigma\vec{F}_x = -0.3392\text{ N (two extra digits carried)}$$

For the y-component of the force,

$$\Sigma\vec{F}_y = \vec{F}_{\text{air}y} + \vec{F}_{\text{g}y}$$
$$= (0.40\text{ N})\sin 32° + (-1.5\text{ N})$$
$$\Sigma\vec{F}_y = -1.288\text{ N (two extra digits carried)}$$

Construct $\Sigma\vec{F}$:

$$\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$$
$$= \tan^{-1}\left(\frac{1.288\ \cancel{\text{N}}}{0.3392\ \cancel{\text{N}}}\right) \text{ (two extra digits carried)}$$
$$\theta = 75°$$

Statement: The magnitude of the net force on the ball is 1.3 N [75° below the horizontal].

5. (a) Since the ball is at rest, the net force on it is 0 N.

(b) If I suddenly remove my hand, the only force acting on the ball is gravity. The net force is 16 N [down].

(c) Given: $\vec{F}_\text{g} = 16$ N [down]; $\vec{F}_\text{a} = 12$ N [right]

Required: $\Sigma\vec{F}$

Analysis: $\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$. Choose forward and up as positive.

Solution: For the x-component of the force,

$$\Sigma\vec{F}_x = \vec{F}_{\text{a}x} + \vec{F}_{\text{g}x}$$
$$= 12\text{ N} + 0\text{ N}$$
$$\Sigma\vec{F}_x = 12\text{ N}$$

For the y-component of the force,

$$\Sigma\vec{F}_y = \vec{F}_{\text{a}y} + \vec{F}_{\text{g}y}$$
$$= (0\text{ N}) + (-16\text{ N})$$
$$\Sigma\vec{F}_y = -16\text{ N}$$

Construct $\Sigma\vec{F}$:

$$\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$$
$$= \sqrt{(12\text{ N})^2 + (16\text{ N})^2}$$
$$\left|\Sigma\vec{F}\right| = 20\text{ N}$$

$$\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$$
$$= \tan^{-1}\left(\frac{16\ \cancel{\text{N}}}{12\ \cancel{\text{N}}}\right)$$
$$\theta = 53°$$

Statement: The net force on the basketball is 20 N [right 53° down].

(d) Given: $\vec{F}_\mathrm{g} = 16$ N [down]; $\vec{F}_\mathrm{a} = 26$ N [up 45° right]

Required: $\Sigma\vec{F}$

Analysis: $\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; $\theta = \tan^{-1}\left(\dfrac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$. Choose forward and up as positive.

Solution: For the x-component of the force,

$$\begin{aligned}
\Sigma\vec{F}_x &= \vec{F}_{\mathrm{a}x} + \vec{F}_{\mathrm{g}x} \\
&= (26\ \mathrm{N})\cos 45° + 0\ \mathrm{N} \\
\Sigma\vec{F}_x &= 18.38\ \mathrm{N}\ \text{(two extra digits carried)}
\end{aligned}$$

For the y-component of the force,

$$\begin{aligned}
\Sigma\vec{F}_y &= \vec{F}_{\mathrm{a}y} + \vec{F}_{\mathrm{g}y} \\
&= (26\ \mathrm{N})\sin 45° + (-16\ \mathrm{N}) \\
\Sigma\vec{F}_y &= -2.385\ \mathrm{N}\ \text{(two extra digits carried)}
\end{aligned}$$

Construct $\Sigma\vec{F}$:

$$\begin{aligned}
\left|\Sigma\vec{F}\right| &= \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2} \\
&= \sqrt{(18.38\ \mathrm{N})^2 + (2.385\ \mathrm{N})^2} \\
\left|\Sigma\vec{F}\right| &= 19\ \mathrm{N}
\end{aligned}$$

$$\begin{aligned}
\theta &= \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right) \\
&= \tan^{-1}\left(\frac{2.385\ \cancel{\mathrm{N}}}{18.38\ \cancel{\mathrm{N}}}\right) \\
\theta &= 7.4°
\end{aligned}$$

Statement: The net force on the basketball is 19 N [right 7.4° up].

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1. Table 1 Common Forces

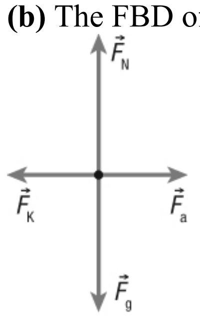
Name	Symbol	Contact/ non-contact	Direction	Example in daily life
force of gravity	$\vec{F}_g$	non-contact	down	A peanut butter sandwich falls to the floor because it is pulled by gravity.
normal force	$\vec{F}_N$	contact	perpendicular to surface	A tea cup sits on the surface of a table, held up by the normal force.
string tension	$\vec{F}_T$	contact	away from object	A child uses tension in a leash to pull her dog.
friction	$\vec{F}_f$	contact	opposite to direction of motion or tendency to motion	Friction in the car brake pads causes the car to slow down.
static friction	$\vec{F}_S$	contact	along the surface, opposite to sum of the other forces	Static friction between a sled and the snow has to be overcome before the sled will slide.
kinetic friction	$\vec{F}_K$	contact	along the surface, opposite to direction of motion	Kinetic friction between my skate blades and the ice causes me to slow down.
air resistance	$\vec{F}_{air}$	contact	opposite to direction of motion	A falling sheet of paper is subject to air resistance as well as the force of gravity.
applied force (push or pull)	$\vec{F}_a$	contact	any direction	My friends help me push my car out of the ditch.

2. A pulley is a device that changes the direction of string tension but does not change its magnitude. This means that the tension in the cord is 22 N throughout. Therefore, the student's statement is not valid.

3. Ropes can only pull and never push because the rope just sags when you push on it and, therefore, you cannot exert a force.

4. (a) The forces acting on the textbook are the force of gravity, the normal force, the applied force, and the force of kinetic friction.

(b) The FBD of the textbook is shown below.



5. Given: $\vec{F}_A = 2.3\text{ N [S 35° W]}$; $\vec{F}_B = 3.6\text{ N [N 14° W]}$; $\vec{F}_C = 4.2\text{ N [S 34° E]}$

(a) Required: $\vec{F}_A + \vec{F}_B + \vec{F}_C$

Analysis: $\vec{F}_A + \vec{F}_B + \vec{F}_C$. Choose north and east as positive.

Solution:
$$\begin{aligned}\Sigma\vec{F}_x &= \vec{F}_{Ax} + \vec{F}_{Bx} + \vec{F}_{Cx}\\ &= (-2.3\text{ N})\sin 35° + (-3.6\text{ N})\sin 14° + (4.2\text{ N})\sin 24°\\ &= -1.319\text{ N} - 0.8709\text{ N} + 1.708\text{ N}\\ \Sigma\vec{F}_x &= -0.4819\text{ N (two extra digits carried)}\end{aligned}$$

$$\Sigma\vec{F}_y = \vec{F}_{Ay} + \vec{F}_{By} + \vec{F}_{Cy}$$
$$= (-2.3\text{ N})\cos 35° + (3.6\text{ N})\cos 14° + (-4.2\text{ N})\cos 24°$$
$$= -1.884\text{ N} + 3.493\text{ N} - 3.836\text{ N}$$
$$\Sigma\vec{F}_y = -2.227\text{ N (two extra digits carried)}$$

Construct $\Sigma\vec{F}$:

$$\left|\Sigma\vec{F}\right| = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$$
$$= \sqrt{(0.4819\text{ N})^2 + (2.227\text{ N})^2}$$
$$\left|\Sigma\vec{F}\right| = 2.3\text{ N}$$

$$\theta = \tan^{-1}\left(\frac{\Sigma\vec{F}_y}{\Sigma\vec{F}_x}\right)$$
$$= \tan^{-1}\left(\frac{2.227\ \cancel{\text{N}}}{0.4819\ \cancel{\text{N}}}\right)$$
$$\theta = 78°$$

Statement: $\vec{F}_A + \vec{F}_B + \vec{F}_C = 2.3\text{ N [W 78° S] or [S 12° W]}$

(b) Required: $\vec{F}_B - \vec{F}_C$

Analysis: $\vec{F}_B - \vec{F}_C$. Choose north and east as positive.

Solution:

For the *x*-component of the force,

$$\left(\vec{F}_B - \vec{F}_C\right)_x = \vec{F}_{Bx} - \vec{F}_{Cx}$$
$$= (-3.6\text{ N})\sin 14° - (4.2\text{ N})\sin 24°$$
$$= -0.8709\text{ N} - 1.708\text{ N}$$
$$\left(\vec{F}_B - \vec{F}_C\right)_x = -2.579\text{ N (two extra digits carried)}$$

For the *y*-component of the force,

$$\left(\vec{F}_B - \vec{F}_C\right)_y = \vec{F}_{By} - \vec{F}_{Cy}$$
$$= (3.6\text{ N})\cos 14° - (-4.2\text{ N})\cos 24°$$
$$= +3.493\text{ N} + 3.836\text{ N}$$
$$\left(\vec{F}_B - \vec{F}_C\right)_y = 7.329\text{ N (two extra digits carried)}$$

Construct $\Sigma\vec{F}$:

$$\left|\vec{F}_{\mathrm{B}}-\vec{F}_{C}\right|=\sqrt{\left(\vec{F}_{\mathrm{B}}-\vec{F}_{\mathrm{C}}\right)_x^2+\left(\vec{F}_{\mathrm{B}}-\vec{F}_{\mathrm{C}}\right)_y^2}$$

$$=\sqrt{(2.579\ \mathrm{N})^2+(7.329\ \mathrm{N})^2}$$

$$\left|\vec{F}_{\mathrm{B}}-\vec{F}_{C}\right|=7.8\ \mathrm{N}$$

$$\theta=\tan^{-1}\left(\frac{\left(\vec{F}_{\mathrm{B}}-\vec{F}_{\mathrm{C}}\right)_y}{\left(\vec{F}_{\mathrm{B}}-\vec{F}_{\mathrm{C}}\right)_x}\right)$$

$$=\tan^{-1}\left(\frac{7.329\ \cancel{\mathrm{N}}}{2.579\ \cancel{\mathrm{N}}}\right)$$

$$\theta=71^\circ$$

Statement: $\vec{F}_{\mathrm{B}}-\vec{F}_{C}=7.8\ \mathrm{N}$ [W 71° N] or [N 19° W]

6. Given: $\vec{F}_{\mathrm{A}}=33\ \mathrm{N}$ [E 22° N]; $\vec{F}_{\mathrm{B}}=42\ \mathrm{N}$ [S 15° E]; $\Sigma\vec{F}=0\ \mathrm{N}$

Required: $\vec{F}_{\mathrm{C}}$

Analysis: $\vec{F}_{\mathrm{A}}+\vec{F}_{\mathrm{B}}+\vec{F}_{\mathrm{C}}=0\ \mathrm{N}$. Choose north and east as positive.

Solution: For the *x*-component of the force,

$$\vec{F}_{\mathrm{C}x}=-\vec{F}_{\mathrm{A}x}-\vec{F}_{\mathrm{B}x}$$

$$=-(33\ \mathrm{N})\cos 22^\circ-(42\ \mathrm{N})\sin 15^\circ$$

$$=-30.60\ \mathrm{N}-10.87\ \mathrm{N}$$

$$\vec{F}_{\mathrm{C}x}=-41.47\ \mathrm{N}\ \text{(two extra digits carried)}$$

For the *y*-component of the force,

$$\vec{F}_{\mathrm{C}y}=-\vec{F}_{\mathrm{A}y}-\vec{F}_{\mathrm{B}y}$$

$$=-(33\ \mathrm{N})\sin 22^\circ-(-42\ \mathrm{N})\cos 15^\circ$$

$$=-12.36\ \mathrm{N}+40.57\ \mathrm{N}$$

$$\vec{F}_{\mathrm{C}y}=28.21\ \mathrm{N}\ \text{(two extra digits carried)}$$

Construct $\vec{F}_{\mathrm{C}}$:

$$\left|\vec{F}_{\mathrm{C}}\right|=\sqrt{(\vec{F}_{\mathrm{C}x})^2+(\vec{F}_{\mathrm{C}y})^2}$$

$$=\sqrt{(41.47\ \mathrm{N})^2+(28.21\ \mathrm{N})^2}\ \text{(two extra digits carried)}$$

$$\left|\vec{F}_{\mathrm{C}}\right|=50\ \mathrm{N}$$

$$\theta = \tan^{-1}\left(\frac{\vec{F}_{Cy}}{\vec{F}_{Cx}}\right)$$

$$= \tan^{-1}\left(\frac{28.21\ \cancel{N}}{41.47\ \cancel{N}}\right)$$

$$\theta = 34°$$

Statement: The force needed so that $\vec{F}_A + \vec{F}_B + \vec{F}_C = 0$ N is 50 N [W 34° N].

7. (a) Given: $\vec{F}_1 = 15$ N [N 24° E]; direction of $\vec{F}_2$ is [S]; direction of $\vec{F}_3$ is [W]; $\Sigma\vec{F} = 0$ N

Required: $|\vec{F}_2|$; $|\vec{F}_3|$

Analysis: $\vec{F}_1 = -\vec{F}_2 - \vec{F}_3$. Choose north and east as positive.

Solution: For the x-components of the force:

$$\vec{F}_{1x} = -\vec{F}_{2x} - \vec{F}_{3x}$$

$$(15\text{ N})\sin 24° = -(0\text{ N}) - \vec{F}_{3x}$$

$$\vec{F}_{3x} = -6.101\text{ N (two extra digits carried)}$$

$$\vec{F}_3 = 6.1\text{ N [W]}$$

For the y-components of the force:

$$\vec{F}_{1y} = -\vec{F}_{2y} - \vec{F}_{3y}$$

$$(15\text{ N})\cos 24° = -\vec{F}_{2y} - (0\text{ N})$$

$$\vec{F}_{2y} = -13.70\text{ N (two extra digits carried)}$$

$$\vec{F}_2 = 14\text{ N [S]}$$

Statement: The second child pulls with a force of 14 N [S] and the third child with a force of 6.1 N [W].

(b) Since the net force was zero when the second child lets go, the new net force has the same magnitude as $\vec{F}_2 = 14$ N but the opposite direction.

Therefore, the net force is 14 N [N].

(c) Given: $\vec{F}_1 = 15$ N [N 24° E]; $\Sigma\vec{F} = 0$ N

Analysis: $\Sigma\vec{F} = \vec{F}_1 + \vec{F}_3$. Choose north and east as positive.

Solution: $\Sigma\vec{F} = \vec{F}_1 + \vec{F}_3$

$$0 = 15\text{N} + \vec{F}_3$$

$$\vec{F}_3 = 0 - 15\text{ N}$$

$$\vec{F}_3 = -15\text{ N}$$

Statement: The third child must exert a force of 15 N [S 24° W] to cancel the force of the first child on her own.

8. Given: $\Sigma\vec{F} = 180$ N [E]; $\vec{F}_1 = 120$ N [E 14° S]

Required: $\vec{F}_2$

Analysis: $\Sigma\vec{F} = \vec{F}_1 + \vec{F}_2$. Choose north and east as positive.

Solution: For the x-components of the force:

$$\vec{F}_{2x} = \Sigma\vec{F}_x - \vec{F}_{1x}$$
$$= (180\text{ N}) - (120\text{ N})\cos 14°$$
$$\vec{F}_{2x} = 63.56\text{ N (one extra digit carried)}$$

For the y-components of the force:

$$\vec{F}_{2\text{y}} = \Sigma\vec{F}_\text{y} - \vec{F}_{1\text{y}}$$
$$= (0\text{ N}) - (120\text{ N})\sin 14°$$
$$\vec{F}_{2\text{y}} = -29.03\text{ N (one extra digit carried)}$$

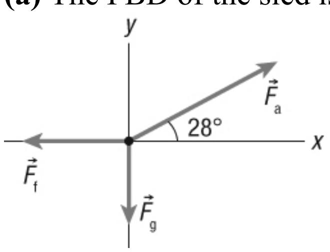
$$\left|\vec{F}_2\right| = \sqrt{(F_{2x})^2 + (F_{2y})^2}$$
$$= \sqrt{(63.56\text{ N})^2 + (29.03\text{ N})^2}$$
$$= 69.88\text{ N (one extra digit carried)}$$
$$\left|\vec{F}_\text{C}\right| = 70\text{ N}$$

$$\theta = \tan^{-1}\left(\frac{\vec{F}_{2y}}{\vec{F}_{2x}}\right)$$
$$= \tan^{-1}\left(\frac{29.03\ \cancel{\text{N}}}{63.56\ \cancel{\text{N}}}\right)$$
$$\theta = 25°$$

Statement: The second student exerts a force of 70 N [E 25° N].

9. Given: $\vec{F}_\text{a} = 55$ N [forward 28° up]; $\vec{F}_\text{g} = 120$ N; $\Sigma\vec{F} = 0$ N

(a) The FBD of the sled is shown below.



(b) Given: $\vec{F}_\text{a} = 55$ N [forward 28° up]; $\vec{F}_\text{g} = 120$ N; $\Sigma\vec{F} = 0$ N

Required: $\vec{F}_\text{N}$

Analysis: $\Sigma\vec{F}_y = \vec{F}_{\text{a}y} + \vec{F}_{\text{g}y} + \vec{F}_{\text{N}y}$. Choose forward and up as positive.

Solution: $\Sigma\vec{F}_y = \vec{F}_{ay} + \vec{F}_{gy} + \vec{F}_{Ny}$

$$0\text{ N} = (55\text{ N})\sin 28° + (-120\text{ N}) + \vec{F}_\text{N}$$

$$\vec{F}_\text{N} = -25.82\text{ N} + 120\text{N}$$

$$= 94.18\text{ N}$$

$$\vec{F}_\text{N} = 94\text{ N}$$

Statement: The normal force acting on the sled is 94 N [up]. The magnitude of the normal force is less than the magnitude of the force of gravity because the applied force has an upward component. In effect, the applied force lifts some of the weight from the surface, reducing the normal force.

(c) Given: $\vec{F}_\text{a} = 55\text{ N}$ [forward 28° up]; $\Sigma\vec{F} = 0\text{ N}$

Required: $\vec{F}_\text{S}$

Analysis: $\Sigma\vec{F}_x = \vec{F}_{ax} + \vec{F}_{Sx}$. Choose forward and up as positive.

Solution: $\Sigma\vec{F}_x = \vec{F}_{ax} + \vec{F}_{Sx}$

$$0\text{ N} = (55\text{ N})\cos 28° - \vec{F}_\text{S}$$

$$\vec{F}_\text{S} = 48.56\text{ N}$$

$$\vec{F}_\text{S} = 49\text{ N}$$

Statement: The force of static friction acting on the sled is 49 N [backward].