4.1

As the ball reaches the top of its path it has no vertical velocity: $v_y = 0$. Also, since the ball has no horizontal velocity relative to the bus, its horizontal velocity relative to the stationary person outside the bus is equal to that of the bus. Hence $\vec{v} = (10\,\mathrm{m/s})$-horizontal.

4.3

The vertical separation between the grapes and the open mouth of Marc Antony is $s_y = 1.0000\,\mathrm{m}$. Since the grapes are released with no initial vertical velocity, their time-of-flight t satisfies $s_y = \frac{1}{2}gt^2$, or $t = \sqrt{2s_y/g}$. In the mean time, the grapes must move horizontally by s_x at a constant speed of $v_x = 2.2136\,\mathrm{m/s}$, so they must be released a horizontal distance s_x from him, where

$$s_x = v_x t = v_x\sqrt{\frac{2s_y}{g}} = (2.2136\,\mathrm{m/s})\sqrt{\frac{2(1.0000\,\mathrm{m})}{9.8000\,\mathrm{m/s^2}}} = 1.0000\,\mathrm{m}\,.$$

4.7

The two persons are pulling each other through the rope with a force of magnitude 100 N. The net force exerted on the person on the left by the the one on the right is 100 N, to the right.

4.8

Horizontally, there is a rightward external force of magnitude 3.0 kN and a leftward external force of 0.50 kN. The net horizontal external force on the truck is then $3.0\,\mathrm{kN} - 0.50\,\mathrm{kN} = 2.5\,\mathrm{kN}$, to the right. Vertically, the net upward force is $2.5\,\mathrm{kN} + 2.5\,\mathrm{kN} = 5.0\,\mathrm{kN}$, while the net downward force is also 5.0 kN. So the net external force in the vertical direction vanishes.

4.9

Since the 100-N force makes an angle of 45° with the positive x-axis, its x-component is $F_{1x} = (100\,\mathrm{N})\cos 45^\circ = 70.7\,\mathrm{N}$, and its y-component is $F_{1y} = (100\,\mathrm{N})\sin 45^\circ = 70.7\,\mathrm{N}$. Similarly, for the 200-N force $F_{2x} = (200\,\mathrm{N})\cos 30^\circ = 173.2\,\mathrm{N}$ and $F_{2y} = (200\,\mathrm{N})\sin 30^\circ = 100\,\mathrm{N}$. Thus the components of the net force $\vec{\mathbf{F}}$ are $F_x = F_{1x} + F_{2x} = 70.7\,\mathrm{N} + 173.2\,\mathrm{N} = 243.9\,\mathrm{N}$ and $F_y = F_{1y} + F_{2y} = 70.7\,\mathrm{N} + 100\,\mathrm{N} = 170.7\,\mathrm{N}$. The magnitude of the equivalent single force $\vec{\mathbf{F}}$ is then

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{(243.9\,\mathrm{N})^2 + (170.7\,\mathrm{N})^2} = 298\,\mathrm{N}\,,$$

and $\vec{\mathbf{F}}$ makes an angle θ with the positive x-direction, where

$$\tan\theta = \frac{F_y}{F_x} = \frac{170.7\,\mathrm{N}}{243.9\,\mathrm{N}} = 0.6999\,,$$

which gives $\theta = +35^\circ$.

4.13

The monkey and the dart start their respective motion at the same instant. Note that the monkey falls vertically so its horizontal position does not change. Suppose that it takes a time t for the dart to close the initial horizontal separation between itself and the monkey. Now, if there were no gravity, then the dart would just move along the line-of-sight. Due to the presence of gravity, however, the actual trajectory of the dart falls *below* the original line-of-sight by an amount $\frac{1}{2}gt^2$ by the time the dart reaches the same horizontal position as the monkey. The monkey, meanwhile, also falls vertically from the line-of-sight by exactly the same amount. So after a time t into the flight the dart and the monkey will be at the same *vertical* as well as *horizontal* position. This is why the dart will get the monkey.

4.22

Due to Newton's Third Law, the net forces exerted on the two magnets are equal in magnitude and opposite in direction. The resulting acceleration of each magnet is inversely proportional to its mass. Since the more massive one (with $m = 2.0\,\mathrm{kg}$) has an acceleration of $(10.0\,\mathrm{m/s^2})$-north, the 1.0-kg mass must have an acceleration in the opposite direction (i.e., due south), of magnitude $(2.0\,\mathrm{kg}/1.0\,\mathrm{kg})(10.0\,\mathrm{m/s^2}) = 20\,\mathrm{m/s^2}$.

4.26

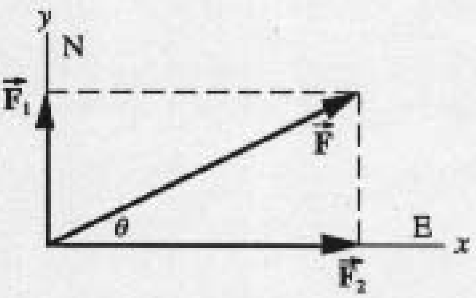
Assuming the acceleration $\vec{a}$ of the lion of mass m to be horizontal, from $\sum \vec{F} = m\vec{a}$ we know that $\vec{a}$ must result from a horizontal force exerted on the lion by the ground. According to Newton's Third Law the lion must exert a reactive force of the same magnitude on the ground. The magnitude F_x of the horizontal force from the lion is therefore

$$F_x = ma_x = (170\,\mathrm{kg})(10\,\mathrm{m/s^2}) = 1.7 \times 10^3\,\mathrm{N} = 1.7\,\mathrm{kN}.$$

(Note that, in addition to the horizontal force calculated above, the lion also exerts a vertical force on the ground due to his weight.)

4.27

From the diagram to the right $\sum F_x = F_{1x} + F_{2x} = F_2 = 120\,\mathrm{N}$ and $\sum F_y = F_{1y} + F_{2y} = F_2 = 50\,\mathrm{N}$. Thus the magnitude of the net force $\vec{F}$ is



$$\begin{aligned} F &= \sqrt{(\sum F_x)^2 + (\sum F_y)^2} \\ &= \sqrt{(120\,\mathrm{N})^2 + (50\,\mathrm{N})^2} \\ &= 130\,\mathrm{N}, \end{aligned}$$

and the angle between $\vec{F}$ and the positive x-axis is given by

$$\tan\theta = \frac{F_y}{F_x} = \frac{50\,\mathrm{N}}{120\,\mathrm{N}} = 0.416\,7,$$

or $\theta = 23°$. The resulting acceleration $\vec{a}$ of the gentleman of mass m has a magnitude of $a = F/m = 130\,\mathrm{N}/100\,\mathrm{kg} = 1.3\,\mathrm{m/s^2}$, and is at 23° N of E.

(Alternatively, you can solve this problem with greater ease if you realize that $\vec{F}_1$, $\vec{F}_2$ and $\vec{F}$ form the three sides of a 5-12-13 right-angled triangle. This immediately leads to $F = 130\,\mathrm{N}$.)

4.39

Consider the deceleration process of the bullet of mass m $(= 10\,\mathrm{g} = 0.010\,\mathrm{kg})$. Before deceleration its initial speed is v_0 $(= 200\,\mathrm{m/s})$, and afterwards its final speed v is of course zero. The average speed v_{av} during the process is then $v_{av} = \frac{1}{2}(v_0 + v) = \frac{1}{2}v_0$. The bullet's displacement during the stage, s (= 20 cm = 0.20 m), then satisfies $s = v_{av}\Delta t$, where $\Delta t = s/v_{av} = 2s/v_0 = 2(0.20\,\text{m})/(200\,\text{m/s}) = 0.0020\,\text{s}$ is the time it took for the bullet to stop inside the block. The change in its speed, meanwhile, is $\Delta v = v - v_0 = -v_0 = -200\,\text{m/s}$, where we chose the direction of motion of the bullet as positive. Thus the average acceleration of the bullet is given by $a_{av} = \Delta v/\Delta t = (-200\,\text{m/s})/(0.0020\,\text{s}) = -1.0 \times 10^5\,\text{m/s}^2$, and the corresponding average force F exerted by the block on the bullet is

$$F_{av} = ma_{av} = (0.010\,\text{kg})(-1.0 \times 10^5\,\text{m/s}^2) = -1.0\,\text{kN}.$$

Here once again the minus sign indicates that the force exerted on the bullet was opposite to its direction of motion. According to Newton's Third Law the force exerted by the bullet on the block is $-F = +1.0\,\text{kN}$, pointing in the direction of motion of the bullet.

4.49

Take the initial direction motion of the trooper as positive. Just before landing on the snow, the initial speed v_0 of the trooper (of mass m) was $v_0 = 120\,\text{mi/h} = (120\,\text{mi/h})(1609\,\text{m/mi}) \times$

$(1\,\text{h}/3600\,\text{s}) = 53.64\,\text{m/s}$. After sinking a depth of $s = 3.5\,\text{ft} = (3.5\,\text{ft})(0.3048\,\text{m/ft}) = 1.0668\,\text{m}$, his final speed was $v = 0$. The average acceleration a_{av} during the deceleration process satisfies $v^2 - v_0^2 = 2a_{av}s$, or $a_{av} = (v^2 - v_0^2)/2s = -v_0^2/2s$. The corresponding average force exerted on the trooper was then

$$F_{av} = ma_{av} = -\frac{mv_0^2}{2s} = -\frac{(90\,\text{kg})(53.64\,\text{m/s})^2}{2(1.0668\,\text{m})} = -1.2 \times 10^5\,\text{N} = -0.12\,\text{MN}.$$

The force was negative, meaning that it was directed upward, opposite to the direction of the initial motion of the trooper. Note that we neglected the effect of the weight of the trooper in the deceleration process since it was much less than F_{av} from the ground.

4.65

Parallel to the incline, the net force exerted on the car is $\sum F_{\parallel} = F_W \sin\theta = mg\sin\theta$, where m is the mass of the car and $\theta = 20°$ is the angle of inclination. Set $\sum F_{\parallel} = ma$ to obtain the acceleration a of the car down the incline: $a = g\sin\theta$. The speed v of the car after sliding down by a distance of $s = 20\,\text{m}$ is then given by $v^2 = 2as$, or

$$v = \sqrt{2as} = \sqrt{2gs\sin\theta} = \sqrt{2(9.81\,\text{m/s}^2)(20\,\text{m})(\sin 20°)} = 12\,\text{m/s}.$$

4.66

(a) The tension F_T on the topmost end of the rope is used to support the weight of both Jamey (J) and Amy (A), who are undergoing no acceleration. Thus

$$F_T = m_J g + m_A g = (100\,\text{kg} + 50.0\,\text{kg})(9.81\,\text{m/s}^2) = 1.47\,\text{kN}\,.$$

(b) The middle point of the rope has only the weight of Jamey to support. So the tension there is

$$F_T = m_J g = (100\,\text{kg} + 50.0\,\text{kg})(9.81\,\text{m/s}^2) = 981\,\text{N}\,.$$

(c) The net upward force exerted on the two-people system is F_T, the tension at the topmost of the rope; and the net downward force is their total weight, $F_W = (m_J + m_A)g$. Taking up as positive, Newton's Second Law for the two-people system reads

$$+\uparrow \sum F_y = F_T - (m_J + m_A)g = (m_J + m_A)a\,,$$

where $a = +9.8\,\text{m/s}^2$. Solve for F_T:

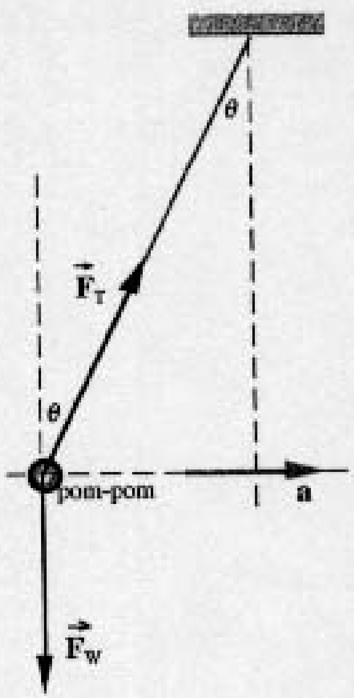
$$F_T = (m_J + m_A)(g + a) = (100\,\text{kg} + 50.0\,\text{kg})(9.8\,\text{m/s}^2 + 9.81\,\text{m/s}^2) = 2.9\,\text{kN}\,.$$

To find F_T in the middle of the rope, we just have to realize that here F_T is responsible only for the upward acceleration of Jamey, rather than both Jamey and Amy. Thus we eliminate m_A from the equation above and obtain

$$F_T = m_J(g + a) = (100\,\text{kg})(9.8\,\text{m/s}^2 + 9.81\,\text{m/s}^2) = 2.0\,\text{kN}\,.$$

4.67

In the figure shown to the right the angle in question is denoted as θ. The pom-pom of mass m has no vertical acceleration and a horizontal acceleration of a. Thus the net vertical force exerted on it must vanish:



$$+\uparrow \sum F_y = F_T \cos\theta - F_W = 0\,,$$

where $F_W = mg$ and F_T is the tension in the string; while the net horizontal force satisfies

$$\overset{+}{\rightarrow} \sum F_x = F_T \sin\theta = ma\,.$$

Rewrite the equation for $\sum F_y$ as $F_T \cos\theta = F_W = mg$, which we now use to divide both sides of the equation for $\sum F_x$. This yields

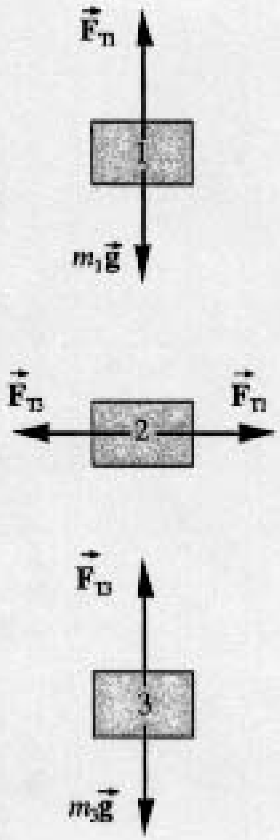
$$\frac{F_T \sin\theta}{F_T \cos\theta} = \tan\theta = \frac{ma}{mg} = \frac{a}{g}\,,$$

or $\tan\theta = a/g$. For $a = \Delta v/\Delta t = (26.8\,\text{m/s})/6.8\,\text{s} = 3.94\,\text{m/s}^2$,

$$\theta = \tan^{-1}\left(\frac{a}{g}\right) = \tan^{-1}\left(\frac{3.94\,\text{m/s}^2}{9.81\,\text{m/s}^2}\right) = 22°\,.$$

4.87

(a) and (b) Free-body diagrams for the three masses are shown to the right. Since $m_1 > m_3$, m_1 will move down, m_3 will move up, while m_2 will move to the right. Taking up to be positive and denoting the common magnitude of the acceleration for all three masses as a, then Newton's Second Law reads



$$+\uparrow\sum F_{y1} = F_{T1} - m_1 g = m_1(-a) = -m_1 a$$

for m_1;

$$\overset{+}{\rightarrow}\sum F_{x2} = F_{T1} - F_{T3} = m_2 a$$

for m_2; and

$$+\uparrow\sum F_{y3} = F_{T3} - m_3 g = m_3 a$$

for m_3. Adding up the last two equations and then subtracting from the result the first equation enables us to eliminate F_{T1} and F_{T3}. The result is $m_1 g - m_3 g = (m_1 + m_2 + m_3)a$, which yields

$$a = \left(\frac{m_1 - m_3}{m_1 + m_2 + m_3}\right)g = \left(\frac{4\,\text{kg} - 2\,\text{kg}}{4\,\text{kg} + 2\,\text{kg} + 2\,\text{kg}}\right)g = \frac{1}{4}g\,.$$

Now plug in the result of a into the equation for m_1 to find F_{T1}:

$$F_{T1} = m_1 g - m_1 a = m_1 g - \frac{1}{4}m_1 g = \frac{3}{4}(4\,\text{kg})(9.81\,\text{m/s}^2) = 0.3 \times 10^2\,\text{N} = 0.03\,\text{kN}\,;$$

and plug in the result of a into the equation for m_3 to find F_{T3}:

$$F_{T3} = m_3 g + m_3 a = m_3 g + \frac{1}{4}m_3 g = \frac{3}{4}(2\,\text{kg})(9.81\,\text{m/s}^2) = 0.2 \times 10^2\,\text{N} = 0.02\,\text{kN}\,.$$

4.96

To drag the garbage can of weight F_W at a uniform speed (i.e., with zero acceleration), you must apply a force F which is equal to its kinetic friction with the road: $F = F_f = \mu_k F_N = \mu_k F_W \propto F_W$. So as the weight of the can (F_W) increases from 100 N to 150 N the corresponding force should also increase by the same proportion, from 40 N to F', where $F'/40\,\text{N} = 150\,\text{N}/100\,\text{N}$. So $F' = 60\,\text{N}$.

4.102

First, find the acceleration of the bottle. Since the bottle (of mass m) slides up the incline, the kinetic friction on the bottle is down the incline. Perpendicular to the incline the acceleration of the bottle is zero: $a_\perp = 0$. So $+\nearrow\sum F_\perp = F_N - F_W\cos\theta = ma_\perp = 0$, where $\theta = 20°$. Parallel to the incline $+\nwarrow\sum F_\parallel = -F_W\sin\theta - F_f = ma_\parallel$, where the minus signs indicate that the directions of both F_f and the component of gravitational force are down the incline. The first equation above gives $F_N = F_W\cos\theta = mg\cos\theta$, which, when substituted into the second equation, yields $-F_W\sin\theta - F_f = -mg\sin\theta - \mu_k mg\cos\theta = ma_\parallel$, or $a_\parallel = -g(\sin\theta + \mu_k\cos\theta)$. Suppose that the bottle can slide up the incline by a displacement of $s_\parallel$, while its speed decreases from v_0 ($= 2.0\,\text{m/s}$) to v ($= 1.0\,\text{m/s}$), then $v^2 - v_0^2 = 2a_\parallel s_\parallel$, and so

$$\begin{aligned} s_\parallel &= \frac{v^2 - v_0^2}{2a_\parallel} = \frac{v^2 - v_0^2}{-2g(\sin\theta + \mu_k\cos\theta)} \\ &= \frac{(1.0\,\text{m/s})^2 - (2.0\,\text{m/s})^2}{-2(9.81\,\text{m/s}^2)\left[\sin 20° + 0.4(\cos 20°)\right]} \\ &= 0.2\,\text{m}\,. \end{aligned}$$

4.106

(a) The force of friction which retards the motion of each crate is given by $F_f = \mu_k F_N = \mu_k F_W$, where F_W is the weight of each crate. With one crate in place, a force of 200 N can cause it to move without acceleration. So $F_f = 200\,\text{N}$ for one crate. With both crates in place, F_f is doubled (since the second one also produces an identical retarding force of $F_f = \mu_k F_W$. So now we need 400 N in order to pull both at a constant speed.

(b) Since μ_k is unchanged but F_N is doubled to $F'_N = 2F_W$, $F_f = \mu_k F'_N = 2(\mu_k F_W) = 2(200\,\text{N}) = 400\,\text{N}$. So again a 400-N pulling force is needed.

4.113

Let the tension in the upper rope be F_{TU} and that in the lower one be F_{TL}. The lower mass (L) is subject to two forces: F_{TL}, upward; and $F_{WL} = m_L g$, downward. Here $m_L = 10\,\text{kg}$. Inasmuch as $a_L = 0$ $\quad +\uparrow \sum F_{yL} = F_{TL} - F_{WL} = m_L a_L = 0$, so

$$F_{TL} = F_{WL} = m_L g = (10\,\text{kg})(9.81\,\text{m/s}^2) = 98\,\text{N}.$$

Similarly, for the upper mass (U) $\quad +\uparrow \sum F_{yU} = F_{TU} - F_{TL} - F_{WU} = m_U a_U = 0$, so

$$F_{TU} = F_{WU} + F_{TL} = m_U g + F_{TL} = (10\,\text{kg})(9.81\,\text{m/s}^2) + 98\,\text{N} = 2.0 \times 10^2\,\text{N} = 0.20\,\text{kN}.$$

4.118

Let the tension in each of the two lower cables be F_T. Then each cable is pulling the steel beam upward with a vertical force of $F_T \sin 70.0°$. Balance of force in the vertical direction for the beam (whose weight is denoted as F_W) then requires that $+\uparrow \sum F_y = 2F_T \sin 70.0° - F_W = 0$; hence

$$F_T = \frac{F_W}{2\sin 70.0°} = \frac{8.00\,\text{kN}}{2\sin 70.0°} = 4.26\,\text{kN}.$$

(As far as the horizontal direction is concerned, you can easily check that the net force is already zero, as long as the tension in the two cables are the same and both cables make the same angle with the horizontal beam.)

4.127

Follow the analysis of the previous problem. For the point on the wire just below the feet of the tightrope walker

$$+\uparrow \sum F_y = 2F_T \sin\theta - F_W,$$

where F_T is the tension in the wire, $F_W = 533.8\,\text{N}$ is her weight, and $\theta = 5.0°$. Hence

$$F_T = \frac{F_W}{2\sin\theta} = \frac{533.8\,\text{N}}{2(\sin 5.0°)} = 3.1 \times 10^3\,\text{N} = 3.1\,\text{kN}.$$

4.134

A fly has only a negligible mass compared with any of the three masses in question. For the tiny fly to upset the balance the system must already be on the verge of moving even before it lands on the 80.0-kg mass. This means that the difference in the tensions exerted by the ropes on the 75.0-kg mass in the middle, $\Delta F_T = (80.0\,\text{kg} - 10.0\,\text{kg})g = -(70.0\,\text{kg})g$, is balanced by the maximum static friction $F_f(\text{max})$ exerted on the mass:

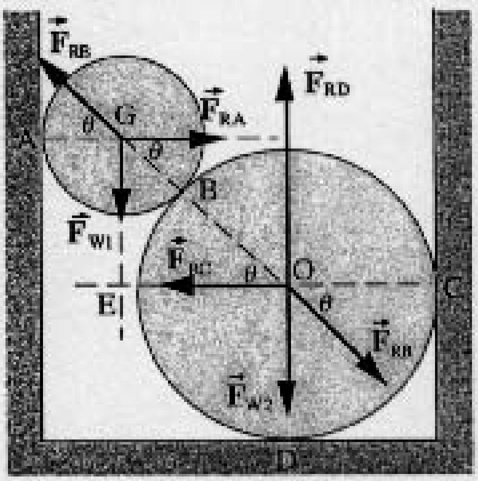
$$F_f(\text{max}) = \mu_s(75.0\,\text{kg})g = \Delta F_T = (70.0\,\text{kg})g\,,$$

which yields

$$\mu_s = \frac{(70.0\,\text{kg})g}{(75.0\,\text{kg})g} = 0.933\,.$$

4.137

Denote the smaller sphere with subscript 1 and the larger one with 2. The various forces exerted on the two spheres are shown to the right. First, determine the angle θ. In the right-angled triangle GOE $\overline{GO} = r_A + r_B = 10.00\,\text{cm} + 20.00\,\text{cm} = 30.0\,\text{cm}$, and $\overline{EO} = 55.98\,\text{cm} - r_1 - r_2 = 55.98\,\text{cm} - 10.00\,\text{cm} - 20.00\,\text{cm} = 25.98\,\text{cm}$. Thus from $\cos\theta = \overline{EO}/\overline{GO} = 25.98\,\text{cm}/30.0\,\text{cm} = 0.866$ we get $\theta = 30.0°$.



Now apply $\sum\vec{F} = 0$ for the smaller sphere (whose weight is F_{w_1}):

$$\begin{cases} \overset{+}{\rightarrow}\sum F_{x1} = F_{RA} - F_{RB}\cos\theta = 0\,, \\ +\!\uparrow\sum F_{y1} = F_{RB}\sin\theta - F_{w_1} = 0\,. \end{cases}$$

Solve for F_{RA} and F_{RB}: $F_{RB} = F_{W1}/\sin\theta = (1.02\,\text{kg})(9.81\,\text{m/s}^2)/\sin 30.0° = 20.0\,\text{N}$; $F_{RA} = F_{RB}\cos\theta = (20.0\,\text{N})(\cos 30.0°) = 17.3\,\text{N}$.

Now balance the forces on the larger sphere (of weight F_{w_2}):

$$\begin{cases} \overset{+}{\rightarrow}\sum F_{x2} = F_{RB}\cos\theta - F_{RC} = 0\,, \\ +\!\uparrow\sum F_{y2} = F_{RD} - F_{RB}\sin\theta - F_{w_2} = 0\,. \end{cases}$$

So $F_{RC} = F_{RB}\cos\theta = (20.0\,\text{N})(\cos 30.0°) = 17.3\,\text{N}$ and $F_{RD} = F_{W2} + F_{RB}\sin\theta = F_{W2} + F_{W1} = (2.04\,\text{kg} + 1.02\,\text{kg})(9.81\,\text{m/s}^2) = 30.0\,\text{N}$.