Forces and the Laws of Motion

ADDITIONAL PRACTICE C

Givens | *Solutions*

1. $v_i = 173$ km/h

$v_f = 0$ km/h

$\Delta x = 0.660$ m

$m = 70.0$ kg

$g = 9.81$ m/s^2

$$a = \frac{v_f^2 - v_i^2}{2\Delta x} = \frac{[(0\text{ km/h})^2 - (173\text{ km/h})^2](10^3\text{ m/km})^2(1\text{ h/3600 s})^2}{(2)(0.660\text{ m})}$$

$a = -1.75 \times 10^3$ m/s^2

$F = ma = (70.0\text{ kg})(-1.75 \times 10^3\text{ m/s}^2) = \boxed{-1.22^{\circ} \times 10^5\text{ N}}$

$F_g = mg = (70.0\text{ kg})(9.81\text{ m/s}^2) = \boxed{6.87 \times 10^2\text{ N}}$

The force of deceleration is nearly 178 times as large as David Purley's weight.

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2. $m = 2.232 \times 10^6$ kg

$g = 9.81$ m/s^2

$a_{net} = 0$ m/s^2

a. $F_{net} = ma_{net} = F_{up} - mg$

$F_{up} = ma_{net} + mg = m(a_{net} + g) = (2.232 \times 10^6\text{ kg})(0\text{ m/s}^2 + 9.81\text{ m/s}^2)$

$F_{up} = \boxed{2.19 \times 10^7\text{ N}} = mg$

b. $F_{down} = mg(\sin\theta)$

$$a_{net} = \frac{F_{net}}{m} = \frac{F_{up} - F_{down}}{m} = \frac{mg - mg(\sin\theta)}{m}$$

$$a_{net} = g(1 - \sin\theta) = (9.81\text{ m/s}^2)[1.00 - (\sin 30.0°)] = \frac{9.81\text{ m/s}^2}{2} = 4.90\text{ m/s}^2$$

$\mathbf{a_{net}} = \boxed{4.90\text{ m/s}^2\text{ up the incline}}$

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3. $m = 40.00$ mg $= 4.00 \times 10^{-5}$ kg

$g = 9.807$ m/s^2

$a_{net} = (400.0)g$

$F_{net} = F_{beetle} - F_g = ma_{net} = m(400.0)\,g$

$F_{beetle} = F_{net} + F_g = m(400.0 + 1)g = m(401)g$

$F_{beetle} = (4.000 \times 10^{-5}\text{ kg})(9.807\text{ m/s}^2)(401) = \boxed{1.573 \times 10^{-1}\text{ N}}$

$F_{net} = F_{beetle} - F_g = m(400.0)\,g = (4.000 \times 10^{-5}\text{ kg})(9.807\text{ m/s}^2)(400.0)$

$F_{net} = \boxed{1.569 \times 10^{-1}\text{ N}}$

The effect of gravity is negligible.

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4. $m_a = 54.0$ kg

$m_w = 157.5$ kg

$a_{net} = 1.00$ m/s^2

$g = 9.81$ m/s^2

The net forces on the lifted weight is

$F_{w,net} = m_w a_{net} = F' - m_w g$

where F' is the force exerted by the athlete on the weight.

The net force on the athlete is

$F_{a,net} = F_{n,1} + F_{n,2} - F' - m_a g = 0$

where $F_{n,1}$ and $F_{n,2}$ are the normal forces exerted by the ground on each of the athlete's feet, and $-F'$ is the force exerted by the lifted weight on the athlete.

The normal force on each foot is the same, so

$F_{n,1} = F_{n,2} = F_n$ and

$F' = 2F_n - m_a g$

Givens	Solutions
	Using the expression for F' in the equation for $F_{w,net}$ yields the following:
	$m_w a_{net} = (2F_n - m_a g) - m_a g$
	$2F_n = m_w(a_{net} + g) + m_a g$
	$F_n = \frac{m_w(a_{net}+g) + m_a g}{2} = \frac{(157.5\text{ kg})(1.00\text{ m/s}^2 + 9.81\text{ m/s}^2) + (54.0\text{ kg})}{2}$
	$F_n = \frac{(157.5\text{ kg})(10.81\text{ m/s}^2) + (54.0\text{ kg})(9.81\text{ m/s}^2)}{2}$
	$F_n = \frac{1702\text{ N} + 5.30 \times 10^2\text{ N}}{2} = \frac{2232\text{ N}}{2} = 1116\text{ N}$
	$F_{n,1} - F_{n,2} = F_n = \boxed{1116\text{ N upward}}$
5. $m = 2.20 \times 10^2$ kg	$F_{net} = ma_{net} = F_{avg} - mg$
$a_{net} = 75.0\text{ m/s}^2$	$F_{avg} = m(a_{net} + g) = (2.20 \times 10^2\text{ kg})(75.0\text{ m/s}^2 + 9.81\text{ m/s}^2)$
$g = 9.81\text{ m/s}^2$	$F_{avg} = (2.20 \times 10^2\text{ kg})(84.8\text{ m/s}^2) = 1.87 \times 10^4\text{ N}$
	$\mathbf{F_{avg}} = \boxed{1.87 \times 10^4\text{ N upward}}$
6. $m = 2.00 \times 10^4$ kg	$a_{net} = \frac{v_f - v_i}{\Delta t} = \frac{(1.0\text{ m/s} - 0.0\text{ m/s})}{2.5\text{ s}} = 0.40\text{ m/s}^2$
$\Delta t = 2.5$	$F_{net} = ma_{net} = F_T - mg$
$v_i = 0$ m/s	$F_T = ma_{net} + mg = m(a_{net} + g)$
$v_f = 1.0$ m/s	$F_T = (2.00 \times 10^4\text{ kg})(0.40\text{ m/s}^2 + 9.81\text{ m/s}^2)$
$g = 9.81\text{ m/s}^2$	$F_T = (2.00 \times 10^4\text{ kg})(10.21\text{ m/s}^2) = 2.04 \times 10^5\text{ N}$
	$F_T = \boxed{2.04 \times 10^5\text{ N}}$
7. $m = 2.65$ kg	$F_{x,net} = F_{T,1}(\cos \theta_1) - F_{T,2}(\cos \theta_2) = 0$
$\theta_1 = \theta_2 = 45.0°$	$F_{T,1}(\cos 45.0°) = F_{T,2}(\cos 45.0°)$
$a_{net} = 2.55\text{ m/s}^2$	$F_{T,1} = F_{T,2}$
$g = 9.81\text{ m/s}^2$	$F_{y,net} = ma_{net} = F_{T,1}(\sin \theta_1) + F_{T,2}(\sin \theta_2) - mg$
	$F_T = F_{T,1} = F_{T,2}$
	$\theta = \theta_1 = \theta_2$
	$F_T(\sin \theta) + F_T(\sin \theta) = m(a_{net} + g)$
	$2F_T(\sin \theta) = m(a_{net} + g)$
	$F_T = \frac{m(a_{net} + g)}{2\ (\sin \theta)} = \frac{(2.65\text{ kg})(2.55\text{ m/s}^2 = 9.81\text{ m/s}^2)}{(2)(\sin 45.0°)}$

Givens	*Solutions*
	$F_T = \frac{(2.65\text{ kg})(12.36\text{ m/s}^2)}{(2)(\sin 45.0°)} = 23.2\text{ N}$ $F_{T,1} = 23.2\text{ N}$ $F_{T,2} = 23.2\text{ N}$
8. $m = 20.0\text{ kg}$ $\Delta x = 1.55\text{ m}$ $v_i = 0\text{ m/s}$ $v_f = 0.550\text{ m/s}$	$a_{net} = \frac{v_f^2 - v_i^2}{2\Delta x} = \frac{(0.550\text{ m/s})^2 - (0.00\text{ m/s})^2}{(2)(1.55\text{ m})} = 9.76 \times 10^{-2}\text{ m/s}^2$ $F_{net} = ma_{net} = (20.0\text{ kg})(9.76 \times 10^{-2}\text{ m/s}^2) = \boxed{1.95\text{ N}}$
9. $m_{max} = 70.0\text{ kg}$ $m = 45.0\text{ kg}$ $g = 9.81\text{ m/s}^2$	$F_{max} = m_{max}g = F_T$ $F_{max} = (70.0\text{ kg})(9.81\text{ m/s}^2) = 687\text{ N}$ $F_{net} = ma_{net} = F_T - mg = F_{max} - mg$ $a_{net} = \frac{F_{max}}{m} - g = \frac{687\text{ N}}{45.0\text{ kg}} - 9.81\text{ m/s}^2 = 15.3\text{ m/s}^2 - 9.81\text{ m/s}^2 = 5.5\text{ m/s}^2$ $\mathbf{a_{net}} = \boxed{5.5\text{ m/s}^2\text{ upward}}$
10. $m = 3.18 \times 10^5\text{ kg}$ $F_{applied} = 81.0 \times 10^3\text{ N}$ $F_{friction} = 62.0 \times 10^3\text{ N}$	$F_{net} = F_{applied} - F_{friction} = (81.0 \times 10^3 - 62.0 \times 10^3\text{ N})$ $F_{net} = 19.0 \times 10^3\text{ N}$ $a_{net} = \frac{F_{net}}{m} = \left(\frac{19.0 \times 10^3\text{ N}}{3.18 \times 10^5\text{ kg}}\right) = \boxed{5.97 \times 10^{-2}\text{ m/s}^2}$
11. $m = 3.00 \times 10^3\text{ kg}$ $F_{applied} = 4.00 \times 10^3\text{ N}$ $\theta = 20.0°$ $F_{opposing} = (0.120)\ mg$ $g = 9.81\text{ m/s}^2$	$F_{net} = ma_{net} = F_{applied}(\cos\theta) - F_{opposing}$ $a_{net} = \frac{F_{applied}(\cos\theta) - (0.120)\ mg}{m}$ $a_{net} = \frac{(4.00 \times 10^3\text{ N})(\cos 20.0°) - (0.120)(3.00 \times 10^3\text{ kg})(9.81\text{ m/s}^2)}{3.00 \times 10^3\text{ kg}}$ $a_{net} = \frac{3.76 \times 10^3\text{ N} - 3.53 \times 10^3\text{ N}}{3.00 \times 10^3\text{ kg}} = \frac{2.3 \times 10^2\text{ N}}{3.00 \times 10^3\text{ kg}}$ $a_{net} = \boxed{7.7 \times 10^{-2}\text{ m/s}^2}$
12. $m_c = 1.600 \times 10^3\text{ kg}$ $m_w = 1.200 \times 10^3\text{ kg}$ $v_i = 0\text{ m/s}$ $g = 9.81\text{ m/s}^2$ $\Delta y = 25.0\text{ m}$	For the counterweight: The tension in the cable is F_T. $F_{net} = F_T - m_w g = m_w a_{net}$ For the car: $F_{net} = m_c g - F_T = m_c a_{net}$ Adding the two equations yields the following:

Givens	*Solutions*
	$m_c g - m_w g = (m_w + m_c)a_{net}$
	$a_{net} = \frac{(m_c - m_w)g}{m_c + m_w} = \frac{(1.600 \times 10^3\ \text{kg} - 1.200 \times 10^3\ \text{kg})(9.81\ \text{m/s}^2)}{1.600 \times 10^3\ \text{kg} + 1.200 \times 10^3\ \text{kg}}$
	$a_{net} = \frac{(4.00 \times 10^2\ \text{kg})(9.81\ \text{m/s}^2)}{2.800 \times 10^3\ \text{kg}} = \boxed{1.40\ \text{m/s}^2}$
	$v_f = \sqrt{2a_{net}\Delta y + v_i^2} = \sqrt{(2)(1.40\ \text{m/s}^2)(25.0\ \text{m}) + (0\ \text{m/s})^2}$
	$v_f = \boxed{8.37\ \text{m/s}}$

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13. $m = 409$ kg
$d = 6.00$ m
$\theta = 30.0°$
$g = 9.81\ \text{m/s}^2$
$F_{applied} = 2080$ N
$v_i = 0$ m/s

a. $F_{net} = F_{applied} - mg(\sin\theta) = 2080\ \text{N} - (409\ \text{kg})(9.81\ \text{m/s}^2)(\sin 30.0°)$

$F_{net} = 2080\ \text{N} - 2010\ \text{N} = 70\ \text{N}$

$\mathbf{F_{net}} = \boxed{70\ \text{N at } 30.0° \text{ above the horizontal}}$

b. $a_{net} = \frac{F_{net}}{m} = \frac{70\ \text{N}}{409\ \text{kg}} = 0.2\ \text{m/s}^2$

$\mathbf{a_{net}} = \boxed{0.2\ \text{m/s}^2 \text{ at } 30.0° \text{ above the horizontal}}$

c. $d = v_i\Delta t + \frac{1}{2}a_{net}\Delta t^2 = (0\ \text{m/s})\Delta t + \frac{1}{2}(0.2\ \text{m/s}^2)\Delta t^2$

$\Delta t = \sqrt{\frac{(2)(6.00\ \text{m})}{(0.2\ \text{m/s}^2)}} = \boxed{8\ \text{s}}$

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14. $a_{max} = 0.25\ \text{m/s}^2$
$F_{max} = 57$ N
$F_{app} = 24$ N

a. $m = \frac{F_{max}}{a_{max}} = \frac{57\ \text{N}}{0.25\ \text{m/s}^2} = \boxed{2.3 \times 10^2\ \text{kg}}$

b. $F_{net} = F_{max} - F_{app} = 57\ \text{N} - 24\ \text{N} = 33\ \text{N}$

$a_{net} = \frac{F_{net}}{m} = \frac{33\ \text{N}}{2.3 \times 10^2\ \text{kg}} = \boxed{0.14\ \text{m/s}^2}$

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15. $m = 2.55 \times 10^3$ kg
$F_T = 7.56 \times 10^3$ N
$\theta_T = -72.3°$
$F_{buoyant} = 3.10 \times 10^4$ N
$F_{wind} = -920$ N
$g = 9.81\ \text{m/s}^2$

a. $F_{x,net} = \Sigma F_x = m a_{x,net} = F_T(\cos\theta_T) + F_{wind}$

$F_{x,net} = (7.56 \times 10^3\ \text{N})[\cos(-72.3°)] - 920\ \text{N} = 2.30 \times 10^3\ \text{N} - 920\ \text{N} = 1.38 \times 10^3\ \text{N}$

$F_{y,net} = \Sigma F_y = m a_{y,net} = F_T(\sin\theta_T) + F_{buoyant} + F_g = F_T(\sin\theta_T) + F_{buoyant} - mg$

$F_{y,net} = (7.56 \times 10^3\ \text{N})[\sin(-72.3°)] = 3.10 \times 10^4\ \text{N} - (2.55 \times 10^3\ \text{kg})(9.81\ \text{m/s}^2)$

$F_{y,net} = -7.20 \times 10^3\ \text{N} + 3.10 \times 10^4\ \text{N} - 2.50 \times 10^4 = -1.2 \times 10^3\ \text{N}$

$F_{net} = \sqrt{(F_{x,net})^2 + (F_{y,net})^2} = \sqrt{(1.38 \times 10^3\ \text{N})^2 + (-1.2 \times 10^3\ \text{N})^2}$

$F_{net} = \sqrt{1.90 \times 10^6\ \text{N}^2 + 1.4 \times 10^6\ \text{N}^2}$

$F_{net} = \sqrt{3.3 \times 10^6\ \text{N}^2} = 1.8 \times 10^3\ \text{N}$

Givens	*Solutions*
	$\theta = \tan^{-1}\left(\frac{F_{y,\,net}}{F_{x,\,net}}\right) = \tan^{-1}\left(\frac{-1.2 \times 10^3\ \text{N}}{1.38 \times 10^3\ \text{N}}\right)$
	$\theta = -41°$
	$\mathbf{F_{net}} = \boxed{1.8 \times 10^3\ \text{N at } 41° \text{ below the horizontal}}$
	b. $a_{net} = \frac{F_{net}}{m} = \frac{1.8 \times 10^3\ \text{N}}{2.55 \times 10^3\ \text{kg}}$
	$a_{net} = \boxed{0.71\ \text{m/s}^2}$
$\Delta y = -45.0\ \text{m}$	
$v_i = 0\ \text{m/s}$	**c.** Because $v_i = 0$
	$\Delta y = \frac{1}{2}\, a_{y,net}\, \Delta t^2$
	$\Delta x = \frac{1}{2}\, a_{x,net}\, \Delta t^2$
	$\Delta x = \frac{a_{x,net}}{a_{y,net}}$ $\quad \Delta y = \frac{a_{net}(\cos\theta)}{a_{net}(\sin\theta)}$ $\quad \Delta y = \frac{\Delta y}{\tan\theta}$
	$\Delta x = \frac{-45.0\ \text{m}}{\tan(-41°)} = \boxed{52\ \text{m}}$

Forces and the Laws of Motion

Problem C

NEWTON'S SECOND LAW

PROBLEM

A 1.5 kg ball has an acceleration of 9.0 m/s^2 to the left. What is the net force acting on the ball?

SOLUTION

Given: m = 1.5 kg

a = 9.0 m/s^2 to the left

Unknown: **F** = ?

Use Newton's second law, and solve for **F.**

$$\Sigma\mathbf{F} = m\mathbf{a}$$

Because there is only one force,

$$\Sigma\mathbf{F} = \mathbf{F}$$

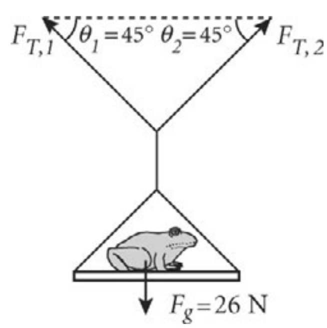
$$F = (1.5\ \text{kg})(9.0\ \text{m/s}^2) = 14\ \text{N}$$

$$\mathbf{F} = 14\ \text{N to the left}$$

ADDITIONAL PRACTICE

1. David Purley, a racing driver, survived deceleration from 173 km/h to 0 km/h over a distance of 0.660 m when his car crashed. Assume that Purley's mass is 70.0 kg. What is the average force acting on him during the crash? Compare this force to Purley's weight. (Hint: Calculate the average acceleration first.)
2. A giant crane in Washington, D. C. was tested by lifting a 2.232×10^6 kg load.
   a. Find the magnitude of the force needed to lift the load with a net acceleration of 0 m/s^2.
   b. If the same force is applied to pull the load up a smooth slope that makes a 30.0° angle with the horizontal, what would be the acceleration?
3. When the click beetle jumps in the air, its acceleration upward can be as large as 400.0 times the acceleration due to gravity. (An acceleration this large would instantly kill any human being.) For a beetle whose mass is 40.00 mg, calculate the magnitude of the force exerted by the beetle on the ground at the beginning of the jump with gravity taken into account. Calculate the magnitude of the force with gravity neglected. Use 9.807 m/s^2 as the value for free-fall acceleration.

4. In 1994, a Bulgarian athlete named Minchev lifted a mass of 157.5 kg. By comparison, his own mass was only 54.0 kg. Calculate the force acting on each of his feet at the moment he was lifting the mass with an upward acceleration of 1.00 m/s^2. Assume that the downward force on each foot is the same.
5. In 1967, one of the high school football teams in California had a tackle named Bob whose mass was 2.20×10^2 kg. Suppose that after winning a game the happy teammates throw Bob up in the air but fail to catch him. When Bob hits the ground, his average upward acceleration over the course of the collision is 75.0 m/s^2. (Note that this acceleration has a much greater magnitude than free-fall acceleration.) Find the average force that the ground exerts on Bob during the collision.
6. The whale shark is the largest type of fish in the world. Its mass can be as large as 2.00×10^4 kg, which is the equivalent mass of three average adult elephants. Suppose a crane lifts a net with a 2.00×10^4 kg whale shark off the ground. The net is steadily accelerated from rest over an interval of 2.5 s until the net reaches a speed of 1.0 m/s. Calculate the magnitude of the tension in the cable pulling the net.
7. The largest toad ever caught had a mass of 2.65 kg. Suppose a toad with this mass is placed on a metal plate that is attached to two cables, as shown in the figure below. If the plate is pulled upward so that it has a net acceleration of 2.55 m/s^2, what is magnitude of the tension in the cables? (The plate's weight can be disregarded.)



8. In 1991, a lobster with a mass of 20.0 kg was caught off the coast of Nova Scotia, Canada. Imagine this lobster involved in a friendly tug of war with several smaller lobsters on a horizontal plane at the bottom of the sea. Suppose the smaller lobsters are able to drag the large lobster, so that after the large lobster has been moved 1.55 m its speed is 0.550 m/s. If the lobster is initially at rest, what is the magnitude of the net force applied to it by the smaller lobsters? Assume that friction and resistance due to moving through water are negligible.
9. A 0.5 mm wire made of carbon and manganese can just barely support the weight of a 70.0 kg person. Suppose this wire is used to lift a 45.0 kg load. What maximum upward acceleration can be achieved without breaking the wire?

10. The largest hydraulic turbines in the world have shafts with individual masses that equal 3.18×10^5 kg. Suppose such a shaft is delivered to the assembly line on a trailer that is pulled with a horizontal force of 81.0 kN. If the force of friction opposing the motion is 62.0 kN, what is the magnitude of the trailer's net acceleration? (Disregard the mass of the trailer.)
11. An average newborn blue whale has a mass of 3.00×10^3 kg. Suppose the whale becomes stranded on the shore and a team of rescuers tries to pull it back to sea. The rescuers attach a cable to the whale and pull it at an angle of 20.0° above the horizontal with a force of 4.00 kN. There is, however, a horizontal force opposing the motion that is 12.0 percent of the whale's weight. Calculate the magnitude of the whale's net acceleration during the rescue pull.
12. One end of the cable of an elevator is attached to the elevator car, and the other end of the cable is attached to a counterweight. The counter-weight consists of heavy metal blocks with a total mass almost the same as the car's. By using the counterweight, the motor used to lift and lower the car needs to exert a force that is only about equal to the total weight of the passengers in the car. Suppose the car with passengers has a mass of 1.600×10^3 kg and the counterweight has a mass of 1.200×10^3 kg. Calculate the magnitude of the car's net acceleration as it falls from rest at the top of the shaft to the ground 25.0 m below. Calculate the car's final speed.
13. The largest squash ever grown had a mass of 409 kg. Suppose you want to push a squash with this mass up a smooth ramp that is 6.00 m long and that makes a 30.0° angle with the horizontal. If you push the squash with a force of 2080 N up the incline, what is
    a. the net force exerted on the squash?
    b. the net acceleration of the squash?
    c. the time required for the squash to reach the top of the ramp?
14. A very thin boron rod with a cross-section of 0.10 mm × 0.10 mm can sustain a force of 57 N. Assume the rod is used to pull a block along a smooth horizontal surface.
    a. If the maximum force accelerates the block by 0.25 m/s^2, find the mass of the block.
    b. If a second force of 24 N is applied in the direction opposite the 57 N force, what would be the magnitude of the block's new acceleration?

15. A hot-air balloon with a total mass of 2.55×10^3 kg is being pulled down by a crew tugging on a rope. The tension in the rope is 7.56×10^3 N at an angle of 72.3° below the horizontal. This force is aided in the vertical direction by the balloon's weight and is opposed by a buoyant force of 3.10×10^4 N that lifts the balloon upward. A wind blowing from behind the crew exerts a horizontal force of 920 N on the balloon.

    a. What is the magnitude and direction of the net force?

    b. Calculate the magnitude of the balloon's net acceleration.

    c. Suppose the balloon is 45.0 m above the ground when the crew begins pulling it down. How far will the balloon travel horizontally by the time it reaches the ground if the balloon is initially at rest?