Conceptual Questions

1. A person sitting in an enclosed train car, moving at constant velocity, throws a ball straight up into the air in her reference frame.
   a) Where does the ball land?
   The ball lands at the same point from which it was thrown inside the train car – back in the thrower’s hand.
   b) Where does the ball land if the car speeds up?
   If the car accelerates, the ball will land behind the point from which it was thrown.
   c) Where does the ball land if the car slows down?
   If the car decelerates, the ball will land in front of the point from which it was thrown.
   d) Where does the ball land if the car rounds a curve?
   If the car rounds a curve (assume it curves to the right), then the ball will land to the left of the point from which it was thrown.
   e) Where does the ball land if the car moves at constant velocity but is open to the air? ¹
   The ball will be slowed by air resistance, and so will land behind the point from which it was thrown.

2. Two rowers, who can row at the same speed in still water, set off across a river at the same time. One heads straight across and is pulled downstream somewhat by the current. The other one heads upstream at an angle so as to arrive opposite the starting point. Which rower reaches the opposite side first? Explain.²
   Both rowers need to cover the same "cross river" distance. The rower with the greatest speed in the "cross river" direction will be the one that reaches the other side first. The current has no bearing on the problem because the current doesn't help either of the boats move across the river. Thus the rower heading straight across will reach the other side first. All of his rowing effort has gone into crossing the river. For the upstream rower, some of his rowing effort goes into battling the current, and so his "cross river" speed will be only a fraction of his rowing speed.

3. Two cannonballs, A and B, are fired from the ground with identical initial speeds, but with θ₁ larger than θ₂.
   a) Which cannonball reaches a higher elevation?
   Cannonball A, with the larger angle, will reach a higher elevation. It has a larger initial vertical velocity, and so by Eq. 2-11c, will rise higher before the vertical component of velocity is 0.
   b) Which stays longer in the air?
   Cannonball A, with the larger angle, will stay in the air longer. It has a larger initial vertical velocity, and so takes more time to decelerate to 0 and start to fall.
   c) Which travels further?³
   The cannonball with a launch angle closest to 45° will travel the farthest. The range is a maximum for a launch angle of 45° and decreases for angles either larger or smaller than 45°.

¹ Physics 6th Edition, Giancoli, Chapter 3 Questions, #15
² Physics 6th Edition, Giancoli, Chapter 3 Questions, #16
³ Physics 6th Edition, Giancoli, Chapter 3 Questions, #20
4. A cannon shoots two cannon balls, A and B, at the same time as shown to the right. The horizontal trajectories are the same, but the maximum altitude of B is about twice that of A. Which ball is traveling faster horizontally at the beginning of its trajectory?  
   a) A  
   b) B  
   c) Same speed  
   d) Not enough information  
   ANS: A
   Since A takes a shorter amount of time to travel the same horizontal distance as B, it must be travelling faster horizontally.

5. Suppose there is a wind blowing parallel to the ground and toward an American football kicker as he is about to kick the ball. The acceleration in the horizontal direction would then be non-zero. How would you expect the time of flight of the football to be affected, if at all? Explain.  
Since the wind is blowing horizontally, it will not affect the vertical motion of the football, so the time of flight will remain the same (though it will travel a shorter distance horizontally).

6. A child is playing on the floor of a recreational vehicle (RV) as it moves along the highway at a constant velocity. He has a toy cannon, which shoots a marble at a fixed angle and speed with respect to the floor. The cannon can be aimed toward the front or the rear of the RV. Is the range toward the front the same as, less than, or greater than the range toward the rear? Answer this question (a) from the child’s point of view and (b) from the point of view of an observer standing still on the ground. Justify your answers.
   a. Since the child is at rest with respect to the floor of the RV and with respect to the cannon, there is no relative motion between the child, the floor of the RV and the cannon. Therefore, the range of the marble toward the front is the same as the range toward the rear from the point of view of the child.

   b. The velocity of the marble relative to an observer standing still on the ground is $v_{MG} = v_{MV} + v_{VG}$, where $v_{MV}$ is the velocity of the marble relative to the vehicle and $v_{VG}$ is the velocity of the vehicle relative to the ground. Suppose that the RV moves in the positive direction; then the quantity $v_{VG}$ is positive. When the marble is shot toward the front of the RV, the x component of $v_{MV}$ will also be a positive quantity. Alternatively, when the marble is shot toward the back of the RV, the x component of $v_{MV}$ is a negative quantity. Thus, the magnitude of the x component of $v_{MG}$ is smaller when the marble is shot toward the rear than when it is shot toward the front. The time that the marble is in the air is determined by the vertical motion which is the same in both cases. Since the magnitude of the x component of $v_{MG}$ is smaller when the marble is shot toward the rear, it will cover less distance in the time it takes to hit the floor of the RV compared to when the marble is shot toward the front. Therefore, from the point of view of an observer on the ground, the range of the marble is greater when the marble is shot toward the front.

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4 Peer Instruction – A User’s Guide, Mazur
5 Physics, 7th Edition, Cutnell & Johnson, Chapter 3 Conceptual Questions, #6
6 Physics, 7th Edition, Cutnell & Johnson, Chapter 3 Conceptual Questions, #15
7. An object is thrown upward at an angle $\theta$ above the ground, eventually returning to earth. (a) Is there any place along the trajectory where the velocity and acceleration are perpendicular? If so, where? (b) Is there any place where the velocity and acceleration are parallel? If so, where? In each case, explain.

An object thrown upward at an angle $\theta$ will follow the trajectory shown below. Its acceleration is that due to gravity, and, therefore, always points downward. The acceleration is denoted by $a_y$ in the figure. In general, the velocity of the object has two components, $v_x$ and $v_y$. Since $a_x = 0$, $v_x$ always equals its initial value. The magnitude of the $y$ component of the velocity, $v_y$, decreases as the object rises, drops to zero at the highest point, and then increases as the object falls downward.

a. Since $v_y = 0$ when the object is at its highest point, the velocity of the object points only in the $x$ direction. As suggested in the figure below, the acceleration will be perpendicular to the velocity when the object is at its highest point and $v_y = 0$.

b. In order for the velocity and acceleration to be parallel, the $x$ component of the velocity would have to drop to zero. However, $v_x$ always remains equal to its initial value; therefore, the velocity and the acceleration can never be parallel.

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7 Physics, 7th Edition, Cutnell & Johnson, Chapter 3 Conceptual Questions, #2
Problems

8. A cannon is set at an angle of $45^\circ$ above the horizontal. A cannonball leaves the muzzle with a speed of $2.2 \times 10^2$ m/s. Air resistance is negligible. Determine the cannonball's

(a) maximum height

Let $+y$ be up.

(a) $v_y = 2.2 \times 10^2$ m/s [45° above the horizontal]

$\alpha_y = -9.8$ m/s$^2$

Find the horizontal and vertical components of the initial velocity:

Horizontally (constant $v_{ix}$):

$v_{ix} = |v| \cos \theta$

$= (2.2 \times 10^2 \text{ m/s}) \cos 45^\circ$

$v_{ix} = 1.6 \times 10^2 \text{ m/s}$

Vertically (constant $a_y$):

$v_{iy} = |v| \sin \theta$

$= (2.2 \times 10^2 \text{ m/s}) \sin 45^\circ$

$v_{iy} = 1.6 \times 10^2 \text{ m/s}$

At the highest position, the $y$-component of the instantaneous velocity is zero ($v_{iy} = 0$ m/s). Thus,

$0 = v_{iy}^2 + 2a_y \Delta y$

$\Delta y = \frac{v_{iy}^2}{-2a_y}$

$= \frac{(1.6 \times 10^2 \text{ m/s})^2}{-2(-9.8 \text{ m/s}^2)}$

$\Delta y = 1.2 \times 10^3 \text{ m}$

The maximum height of the cannonball is $1.2 \times 10^3$ m.

(b) time of flight

$\Delta t = ?$

$\Delta y = v_{iy} \Delta t + \frac{1}{2} \alpha_y (\Delta t)^2$

$0 = (1.6 \times 10^2 \text{ m/s}) \Delta t - 4.9 \text{ m/s}^2 (\Delta t)^2$

$\Delta t = 0$ or $(1.6 \times 10^2 \text{ m/s} - 4.9 \text{ m/s}^2 \Delta t) = 0$

$\Delta t = \frac{1.6 \times 10^2 \text{ m/s}}{4.9 \text{ m/s}^2}$

$\Delta t = 32 \text{ s}$

Therefore, the cannonball was fired at $\Delta t = 0$ and the cannonball lands at $\Delta t = 32$ s.
(c) **horizontal range (to the same vertical level)**

\[
\Delta x = v_{i_x} \Delta t = (1.6 \times 10^2 \text{ m/s})(32 \text{ s}) = 4.9 \times 10^3 \text{ m}
\]

The horizontal range is \(4.9 \times 10^3\) m.

(d) **velocity at impact**

The final velocity has the same magnitude as the initial velocity, but is at an angle of 45° below the horizontal. Thus, the final velocity is \(2.2 \times 10^2 \text{ m/s}\) [45° below the horizontal].

9. **A child throws a ball onto the roof of a house, then catches it with a baseball glove 1.0 m above the ground, as shown to the right. The ball leaves the roof with a speed of 3.2 m/s.**

(a) **For how long is the ball airborne after leaving the roof?**

Let \(+y\) be down. Determine the horizontal and vertical components of:

- **Horizontally (constant \(v_{i_x}\)):**
  
  \[
  v_{i_x} = |v_i| \cos \theta = (3.2 \text{ m/s})(\cos 33^\circ) = 2.7 \text{ m/s}
  \]

- **Vertically (constant \(a_y\)):**

  \[
  v_{i_y} = |v_i| \sin \theta = (3.2 \text{ m/s})(\sin 33^\circ) = 1.7 \text{ m/s}
  \]

  \[
  \Delta y = 6.2 \text{ m} - 1.0 \text{ m} = 5.2 \text{ m}
  \]

  \[
  \Delta y = v_{i_y} \Delta t + \frac{1}{2} a_y (\Delta t)^2 \\
  0 = (9.8 \text{ m/s}^2)(\Delta t)^2 + 1.7 \text{ m/s} \Delta t - 5.2 \text{ m}
  \]

  Solve using the solution to the quadratic equation:

  \[
  \Delta t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{(where } a = 4.9 \text{ m/s}^2, \ b = 1.7 \text{ m/s} \text{, } c = -5.2 \text{)}
  \]

  \[
  \Delta t = 0.87 \text{ s}
  \]

  The ball is airborne for 0.87 s.
(b) What is the horizontal distance from the glove to the edge of the roof?

\[ \Delta x = \gamma \]
\[ = (2.7 \text{ m/s})(0.87 \text{ s}) \]
\[ = 2.3 \text{ m} \]

The child should hold the glove 2.3 m from the edge of the roof.

(c) What is the velocity of the ball just before it lands in the glove? \(^9\)

\[ v_y = v_{ty} + a_y \Delta t \]
\[ v_y = \sqrt{(1.7 \text{ m/s})^2 + 2(9.8 \text{ m/s}^2)(5.2 \text{ m})} \]
\[ v_y = 10.2 \text{ m/s} \]
\[ v_x = v_{tx} = 2.7 \text{ m/s} \]
\[ |v_t| = \sqrt{v_x^2 + v_y^2} \]
\[ = \sqrt{(2.7 \text{ m/s})^2 + (10.2 \text{ m/s})^2} \]
\[ |v_t| = 11 \text{ m/s} \]
\[ \tan \theta = \frac{v_{ty}}{v_{tx}} \]
\[ \theta = \tan^{-1} \left( \frac{10.2 \text{ m/s}}{2.7 \text{ m/s}} \right) \]
\[ \theta = 75^\circ \]

The ball’s final velocity just before it lands in the glove is 11 m/s [75° below the horizontal].

10. A bag of mail is catapulted from the top of a building 200.0 m above the ground with a velocity of 20.0 m/s at an angle of 15° above the horizontal. If the mail is to land on the roof of another building 100.0 m away, how tall is the second building? \(^10\)

Find the time it takes the mail to reach the second building:

\[ d_x = v_{tx}t + \frac{1}{2}a_xt^2 \]
\[ 100 \text{ m} = [(20 \text{ m/s}) \cos 15^\circ]t + \frac{1}{2}(0 \text{ m/s}^2)t^2 \]
\[ t = 5.2 \text{ s} \]

Find the drop in height during the 5.2 s:

\[ \Delta h = v_{ty}t + \frac{1}{2}a_yt^2 \]
\[ \Delta h = [(20.0 \text{ m/s}) \sin 15^\circ](5.2 \text{ s}) + \frac{1}{2}(-9.8 \text{ m/s}^2)(5.2 \text{ s})^2 \]
\[ \Delta h = 26.9 \text{ m} - 132.5 \text{ m} \]
\[ \Delta h = -105 \text{ m} \]

Find the height of the second building:

\[ h_{2nd \text{ building}} = h_{1st \text{ building}} + \Delta h \]
\[ h_{2nd \text{ building}} = 200 \text{ m} - 105 \text{ m} \]
\[ h_{2nd \text{ building}} = 95 \text{ m} \]

The second building is 95 m high.

\(^9\) Physics 12, Nelson Education, Section 1.4 Questions, #5
\(^10\) Physics Book Two, Irwin Publishing, Chapter 2 Problems, #32
11. A stunt-man is trying to cross a piranha infested pool of water in his Humvee. He races up a ramp inclined at 20° to the horizontal at a speed of 30.0 m/s. There is an identical ramp on the other side of the pool. What is the maximum width of the pool that the stunt-man can successfully cross?\textsuperscript{11}

Find the time it takes the Humvee to drop down to the other ramp:

\[
h = v_y t + \frac{1}{2} a_y t^2
\]

Since both ramps are the same height, \( h = 0 \) m.

\[
0 \text{ m} = [(30 \text{ m/s}) \sin 20^\circ] t + \frac{1}{2} (-9.8 \text{ m/s}^2) t^2
\]

\[
[(30 \text{ m/s}) \sin 20^\circ] t = \frac{1}{2} (-9.8 \text{ m/s}^2) t^2
\]

\[
t = 2.1 \text{ s}
\]

Find the maximum horizontal distance the Humvee can travel in 2.1 s:

\[
d_x = v_x t + \frac{1}{2} a_x t^2
\]

\[
d_x = [(30 \text{ m/s}) \cos 20^\circ] (2.1 \text{ s}) + \frac{1}{2} (0 \text{ m/s}^2) (2.1 \text{ s})^2
\]

\[
d_x = 59 \text{ m}
\]

The maximum width of the pool is 59 m.

12. A soccer ball is kicked from the ground at an angle \( \theta \) above the horizontal. Show that the equation \( h = 0.25R \tan \theta \) represents the maximum height of the ball, where \( h \) is the height and \( R \) is the range.\textsuperscript{12}

Find the time required to reach maximum height:

\[
h = v_y t + \frac{1}{2} a_y t^2
\]

\[
h = (v_i \sin \theta) t + \frac{1}{2} a_y (2t)^2
\]

\[
- a_y 2t = (v_i \sin \theta) 2t
\]

\[
- a_y t = v_i \sin \theta
\]

\[
a_y = \frac{-v_i \sin \theta}{t}
\]

(eq. 2)

For the range, \( R \):

\[
R = v_x 2t + \frac{1}{2} a_x (2t)^2
\]

\[
R = v_i \cos \theta 2t + \frac{1}{2} (0 \text{ m/s}^2) (2t)^2
\]

\[
R = v_i 2t
\]

\[
t = \frac{R}{2v_i \cos \theta}
\]

(eq. 3)

Substitute equation 1 into equation 2:

\[
h = (v_i \sin \theta) t + \frac{1}{2} \left( \frac{-v_i \sin \theta}{t} \right) t^2
\]

\[
h = (v_i \sin \theta) t - \frac{1}{2} (v_i \sin \theta) t
\]

\[
h = \frac{1}{2} (v_i \sin \theta) t
\]

(eq. 4)

Substitute equation 3 into equation 4,

\[
h = \frac{1}{2} (v_i \sin \theta) \left( \frac{-R}{2v_i \cos \theta} \right)
\]

\[
h = \frac{1}{4} \left( \frac{\sin \theta}{\cos \theta} \right) R
\]

\[
h = \frac{1}{4} (\tan \theta) R
\]

\[
h = 0.25R \tan \theta
\]

\textsuperscript{11} Physics Book Two, Irwin Publishing, Chapter 2 Problems, #34

\textsuperscript{12} Physics Book Two, Irwin Publishing, Chapter 2 Problems, #35
13. A baseball player makes perfect contact with the ball, striking it 45° above the horizontal at a point 1.3 m above the ground. His home-run hit just clears the 3.0-m wall 130 m from home plate. With what velocity did the baseball player strike the ball?^{13}

If the ball clears the 3.0-m wall 130 m from home plate, then the ball rises

\[(3.0 \text{ m} - 1.3 \text{ m}) = 1.7 \text{ m} \text{ during this time.}\]

Thus, for the vertical height:

\[h = v_i t + \frac{1}{2} a_s t^2\]

\[1.7 \text{ m} = v_i (\sin 45°) t + \frac{1}{2} (-9.8 \text{ m/s}^2) t^2 \quad \text{(eq. 1)}\]

Find the time it takes the ball to clear the wall:

\[d_x = v_i t + \frac{1}{2} a_s t^2\]

\[130 \text{ m} = v_i (\cos 45°) t\]

\[t = \frac{130 \text{ m}}{v_i \cos 45°} \quad \text{(eq. 2)}\]

Substitute equation 2 into equation 1:

\[1.7 \text{ m} = (v_i \sin 45°) \left( \frac{130 \text{ m}}{v_i \cos 45°} \right) + \frac{1}{2} (-9.8 \text{ m/s}^2) \left( \frac{130 \text{ m}}{v_i \cos 45°} \right)^2\]

\[1.7 \text{ m} = (\tan 45°) (130 \text{ m}) - \left( \frac{33800 \text{ m}}{v_i^2} \right)\]

\[v_i = 36 \text{ m/s}\]

The player strikes the ball at 36 m/s, 45° above the horizontal.

14. A swimmer, who can swim at a maximum speed of 1.8 km/h, swims heading straight north across a river of width 0.80 km. If the river’s current is 0.50 km/h

a) how long does it take the swimmer to cross the river?

The current velocity has no effect on the vertical component of the swimmer’s velocity, which is needed for crossing the river.

Therefore:

\[t = \frac{d}{v_s}\]

\[t = \frac{0.80 \text{ km}}{1.8 \text{ km/h}}\]

\[t = 0.44 \text{ h}\]

b) how far downstream will the swimmer land?

The current velocity determines how far the swimmer travels downstream, therefore:

\[d_d = (v_c)(t)\]

\[d_d = (0.50 \text{ km/h})(0.44 \text{ h})\]

\[d_d = 0.22 \text{ km}\]

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^{13} Physics Book Two, Irwin Publishing, Chapter 2 Problems, #36
c) what is the swimmer’s ground velocity\textsuperscript{14}

\[ v_g = \sqrt{v_s^2 + v_c^2} \]

\[ v_g = \sqrt{(1.8 \text{ km/h})^2 + (0.5 \text{ km/h})^2} \]

\[ v_g = 1.9 \text{ km/h} \]

\[ \tan \theta = \frac{v_c}{v_s} \]

\[ \theta = \tan^{-1}\left(\frac{0.5 \text{ km/h}}{1.8 \text{ km/h}}\right) \]

\[ \theta = 16^\circ \]

The ground velocity is \( \vec{v}_g = 1.9 \text{ km/h} \) [N16\(^\circ\)E].

15. If the swimmer from problem #22 decided to change his direction so as to go straight north, determine

a) his heading

In order to go north, his ground velocity must be north.

\[ \vec{v}_g \]

b) his ground velocity

\[ v_g = \sqrt{v_s^2 - v_c^2} \]

\[ v_g = \sqrt{(1.8 \text{ km/h})^2 - (0.5 \text{ km/h})^2} \]

\[ v_g = 1.7 \text{ km/h} \]

His ground velocity is \( \vec{v}_g = 1.7 \text{ km/h} \) [N].

c) the amount of time it would take him to cross the river.\textsuperscript{15}

\[ t = \frac{d}{v_g} \]

\[ t = \frac{0.8 \text{ km}}{1.7 \text{ km/h}} \]

\[ t = 0.46 \text{ h} \]

\textsuperscript{14} Physics Book Two, Irwin Publishing, Chapter 2 Problems, #22

\textsuperscript{15} Physics Book Two, Irwin Publishing, Chapter 2 Problems, #23
16. A ship's captain wishes to sail his ship north-east. A current is moving his ship with a velocity of 5.0 km/h [S]. If the ship has a maximum speed of 30 km/h, what is the ship's required heading? \(^6\)

![Diagram showing the ship's and current's velocities.]  

Use the sine law to find \(\theta\):

\[
\frac{\sin \theta}{v_c} = \frac{\sin \beta}{v_s}
\]

\[
\theta = \sin^{-1}\left(\frac{v_c \sin \beta}{v_s}\right)
\]

\[\theta = 6.8^\circ\]

Use the sum of the interior angles of a triangle to find \(\gamma\):

\[\theta + \beta + \gamma = 180^\circ\]

\[\gamma = 180^\circ - \theta - \beta\]

\[\gamma = 180^\circ - 135^\circ - 6.8^\circ\]

\[\gamma = 38^\circ\]

The ship's required heading is [N38°E].

17. A cruise ship is sailing north at a speed of 10 km/h. A passenger walks along the deck with a velocity of 0.5 m/s towards the stern of the ship. She then turns toward port and walks top the railing at the same speed. Determine the passenger’s velocity for both motions

a) relative to the ship

Since the velocities are given relative to the deck, they are the velocities relative to the ship.

Walking towards stern: \(\vec{v} = 0.5 \text{ m/s [S]}\);
walking towards port, \(\vec{v} = 0.5 \text{ m/s [W]}\).
b) relative to the water\textsuperscript{17}

\[
\vec{v}_{pw} = \vec{v}_{ps} + \vec{v}_{sw}
\]

Walking towards stern:
\[
\vec{v}_{pw} = \vec{v}_{ps} + \vec{v}_{sw}
\]
\[
\vec{v}_{pw} = 0.5 \text{ m/s [S]} + 10 \text{ km/h [N]}
\]
\[
\vec{v}_{pw} = -0.5 \text{ m/s [N]} + 2.78 \text{ m/s [N]}
\]
\[
\vec{v}_{pw} = 2.3 \text{ m/s [N]}
\]

Walking towards port:
\[
\vec{v}_{pw} = \vec{v}_{ps} + \vec{v}_{sw}
\]
\[
\vec{v}_{pw} = 0.5 \text{ m/s [W]} + 2.78 \text{ m/s [N]}
\]
\[
\vec{v}_{pw} = \sqrt{v_{ps}^2 + v_{sw}^2}
\]
\[
\vec{v}_{pw} = \sqrt{(0.5 \text{ m/s})^2 + (2.78 \text{ m/s})^2}
\]
\[
\vec{v}_{pw} = 2.8 \text{ m/s}
\]

\[\tan \theta = \frac{v_{ps}}{v_{sw}}\]
\[\theta = \tan^{-1} \left( \frac{0.5 \text{ m/s}}{2.78 \text{ m/s}} \right)\]
\[\theta = 10^\circ\]

Walking towards stern, \(\vec{v} = 2.3 \text{ m/s [N]};\)
walking towards port, \(\vec{v} = 2.8 \text{ m/s [N10^\circ W]}\).

18. A rock is thrown horizontally from a height of 35 m from the roof of a library and travels through the air. A wind is blowing with a constant velocity of 11.5 m/s [N25°W]. The rock ends up breaking a window of a financial building, 3.5 m above the ground. If the thrower released the rock with a velocity of 18 m/s [E15°N], determine the location of the financial building in reference to the base of the library.\textsuperscript{18}

\[
\vec{v}_{og} = \vec{v}_{om} + \vec{v}_{mg}
\]
\[
\vec{v}_{om} = 18 \text{ m/s [E15°N]}
\]
\[
\vec{v}_{mg} = 11.5 \text{ m/s [N25°W]}
\]

\[
18 \text{ m/s}
\]

\[
11.5 \text{ m/s}
\]

\[
\vec{v}_{og} = \sqrt{a^2 + b^2 - 2ab \cos 80^\circ}
\]
\[
\vec{v}_{og} = \sqrt{(18 \text{ m/s})^2 + (11.5 \text{ m/s})^2 - 2(18 \text{ m/s})(11.5 \text{ m/s}) \cos 80^\circ}
\]
\[
\vec{v}_{og} = 19.605 \text{ m/s}
\]

\textsuperscript{17} Physics Book Two, Irwin Publishing, Chapter 2 Problems, #27

\textsuperscript{18}
\[
\begin{align*}
\sin a &= \frac{18 \text{ m/s}}{19.605 \text{ m/s}} = \sin 80^\circ \\
a &= \sin^{-1}\left(\frac{18 \text{ m/s}}{19.605 \text{ m/s}}\sin 80^\circ\right) = 65^\circ \\
a - 25^\circ &= 65^\circ - 25^\circ = 40^\circ \\
\vec{v}_{og} &= 19.605 \text{ m/s} [N40^\circ E]
\end{align*}
\]

<table>
<thead>
<tr>
<th>x (horizontal)</th>
<th>y (vertical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\ddot{a} = 0)</td>
<td>(\ddot{a} = 9.8 \text{ m/s}^2 \downarrow)</td>
</tr>
<tr>
<td>(\vec{v} = 19.605 \text{ m/s} [N40^\circ E])</td>
<td>(\vec{v}_1 = 0 \text{ m/s} \downarrow)</td>
</tr>
<tr>
<td>(\Delta t = ?)</td>
<td>(\Delta t = ?)</td>
</tr>
<tr>
<td>(\Delta \vec{d} = ?)</td>
<td>(\Delta \vec{d} = 31.5 \text{ m} \downarrow)</td>
</tr>
</tbody>
</table>

From y:

\[
\begin{align*}
\Delta \vec{d} &= \vec{v}_1 \Delta t + \frac{1}{2} \ddot{\vec{d}} \Delta t^2 \\
\Delta t &= \sqrt{\frac{2(31.5 \text{ m} \downarrow)}{9.8 \text{ m/s}^2 \downarrow}} \\
\Delta \vec{d} &= 49.708 \text{ m} [N40^\circ E] \\
\Delta \vec{d} &= 5.0 \times 10^1 \text{ m} [N40^\circ E]
\end{align*}
\]

From x:

\[
\begin{align*}
\Delta \vec{d} &= \vec{v} \Delta t + \frac{1}{2} \ddot{\vec{d}} \Delta t^2 \\
\Delta \vec{d} &= (19.605 \text{ m/s} [N40^\circ E])(2.535 \text{ s}) \\
\Delta \vec{d} &= (19.605 \text{ m/s} [N40^\circ E])(2.535 \text{ s})
\end{align*}
\]