Chapter 2: One-Dimensional Kinematics

Answers to Conceptual Questions

**116.** Can you drive your car in such a way that the distance it covers is (a) greater than, (b) equal to, or (c) less than the magnitude of its displacement? In each case, give an example if your answer is yes, explain why not if your answer is no.

(a) Yes. If you drive in a complete circle your distance is the circumference of the circle, but your displacement is zero. (b) Yes. The distance and the magnitude of the displacement are equal if you drive in a straight line. (c) No. Any deviation from a straight line results in a distance that is greater than the magnitude of the displacement.

**117.** CE **Predict/Explain** You drive your car in a straight line at 15 m/s for 10 minutes, then at 25 m/s for another   
10 minutes. **(a)** Is your average speed for the entire trip more than, less than, or equal to 20 m/s? **(b)** Choose the *best* explanation from among the following:

**I.** More time is required to drive at 15 m/s than at 25 m/s.

**II.** Less distance is covered at 25 m/s than at 15 m/s.

**III.** Equal time is spent at 15 m/s and 25 m/s.

Yes. For example, your friends might have backed out of a parking place at some point in the trip, giving a negative velocity for a short time.

**118.** In 1992 Zhuang Yong of China set a women’s Olympic record in the 100-meter freestyle swim with a time of 54.64 seconds. What was her average speed in m/s and mi/h?

No. If you throw a ball upward, for example, you might choose the release point to be *y* = 0. This doesn’t change the fact that the initial upward speed is nonzero.

**119.** A finch rides on the back of a Galapagos tortoise, which walks at the stately pace of 0.060 m/s. After 1.2 minutes the finch tires of the tortoise’s slow pace, and takes flight in the same direction for another 1.2 minutes at 12 m/s. What was the average speed of the finch for this 2.4-minute interval?

Ignoring air resistance, the two gloves have the same acceleration.

**Solutions to Problems and Conceptual Exercises**

**120.** In 1992 Zhuang Yong of China set a women’s Olympic record in the 100-meter freestyle swim with a time of 54.64 seconds. What was her average speed in m/s and mi/h?

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: The swimmer swims in the forward direction. | |
|  | **Strategy:** The average speed is the distance divided by elapsed time. | |
|  | **Solution:** Divide the distance by the time: |  |
|  | **Insight:** The displacement would be zero in this case because the swimmer swims either two lengths of a 50-m pool or four lengths of a 25-m pool, returning to the starting point each time. However, the average speed depends upon distance traveled, not displacement. | |

**121.** Estimate how fast your hair grows in miles per hour.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: Your hair grows at a fixed speed. | |
|  | **Strategy:** The growth rate is the length gained divided by the time elapsed. Hair grows at a rate of about half an inch a month, or about 1 cm or 0.01 m per month. | |
|  | **Solution:** Divide the length gained by the elapsed time: |  |
|  | **Insight:** Try converting this growth rate to a more appropriate unit such as *µ*m/h. (Answer: 14 *µ*m/h.) Choosing an appropriate unit can help you communicate a number more effectively. | |

**122.** **IP** You drive in a straight line at 20.0 m/s for 10.0 minutes, then at 30.0 m/s for another 10.0 minutes. **(a)** Is your average speed 25.0 m/s, more than 25.0 m/s, or less than 25.0 m/s? Explain. **(b)** Verify your answer to part (a) by calculating the average speed.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: You travel in a straight line at two different speeds during the specified time interval. | |
|  | **Strategy:** Determine the average speed by first calculating the total distance traveled and then dividing it by the total time elapsed. | |
|  | **Solution:** **1. (a)** Because the time intervals are the same, you spend equal times at 20 m/s and 30 m/s, and your average speed will be equal to 25.0 m/s. | |
|  | **2.** **(b)** Divide the total distance  by the time elapsed: |  |
|  | **Insight:** The average speed is a weighted average according to how much *time* you spend traveling at each speed. | |

**123.** **IP** You drive in a straight line at 20.0 m/s for 10.0 miles, then at 30.0 m/s for another 10.0 miles. **(a)** Is your average speed 25.0 m/s, more than 25.0 m/s, or less than 25.0 m/s? Explain. **(b)** Verify your answer to part (a) by calculating the average speed.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: You travel in a straight line at two different speeds during the specified time interval. | |
|  | **Strategy:** Determine the average speed by first calculating the total distance traveled and then dividing it by the total time elapsed. | |
|  | **Solution:** **1. (a)** The distance intervals are the same but the time intervals are different. You will spend more time at  the lower speed than at the higher speed. Because the average speed is a time weighted average, it will be less than 25.0 m/s. | |
|  | **2.** **(b)** Divide the total distance by the time elapsed: |  |
|  | **Insight:** Notice that in this case it is not necessary to convert miles to meters in both the numerator and denominator because the units cancel out and leave m/s in the numerator. | |

**124.** **CE** **Predict/Explain** Two bows shoot identical arrows with the same launch speed. To accomplish this, the string in bow 1 must be pulled back farther when shooting its arrow than the string in bow 2. **(a)** Is the acceleration of the arrow shot by bow 1 greater than, less than, or equal to the acceleration of the arrow shot by bow 2? **(b)** Choose the *best explanation* from among the following:

**I.** The arrow in bow 2 accelerates for a greater time.

**II.** Both arrows start from rest.

**III.** The arrow in bow 1 accelerates for a greater time.

|  |  |
| --- | --- |
|  | **Picture the Problem**: Two arrows are launched by two different bows. |
|  | **Strategy:** Use the definitions of average speed and acceleration to compare the motions of the two arrows. |
|  | **Solution:**  **1. (a)** We can reason that because both arrows undergo uniform acceleration between the same initial and final velocities, both arrows must have the same average speed. If they have the same average speed, then arrow 1, which must travel a longer distance, will be accelerated for a longer period of time. We conclude that the acceleration of the arrow shot by bow 1 is less than the acceleration of the arrow shot by bow 2. |
|  | **2. (b)** As discussed above, the best explanation is **III**. The arrow in bow 1 accelerates over a greater time. Statement I is false and statement II is true but is not a complete explanation. |
|  | **Insight:** We could also set in the equation, and solve for *a*:  From this expression we can see that for the same final velocity *v*, the arrow that is accelerated over the greater distance  will have the smaller acceleration. |

**125.** **IP** In the previous problem, **(a)** does the distance needed to stop increase by a factor of two or a factor of four? Explain. Verify your answer to part (a) by calculating the stopping distances for initial speeds of **(b)** 16 m/s and **(c)** 32 m/s.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: The car travels in a straight line in the positive direction while accelerating in the negative direction (slowing down). | |
|  | **Strategy:** Use the average velocity and the time elapsed to determine the distance traveled for the specified change in velocity. | |
|  | **Solution:**  **1. (a)** Because the distance traveled is proportional to the square of the time (Equation 2-11), or alternatively, because both the time elapsed and the average velocity change by a factor of two, the stopping distance will increase by a factor of four when you double your driving speed. | |
|  | **2. (b)** Evaluate Equation 2-10 directly: |  |
|  | **3. (c)** Evaluate Equation 2-10 directly: |  |
|  | **Insight:** Doubling your speed will quadruple the stopping distance for a constant acceleration. We will learn in chapter 7 that this can be explained in terms of energy; that is, doubling your speed quadruples your kinetic energy. | |

**126.** Suppose the car in Problem 44 comes to rest in 35 m. How much time does this take?

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: The car travels in a straight line toward the west while accelerating in the easterly direction (slowing down). | |
|  | **Strategy:** The average velocity is simply half the sum of the initial and final velocities because the acceleration is uniform. Use the average velocity together with Equation 2-10 to find the time. | |
|  | **Solution:** Solve Equation 2-10 for time: |  |
|  | **Insight:** The distance traveled is always the average velocity multiplied by the time. This stems from the definition of average velocity. | |

**127.** **Air Bags** Air bags are designed to deploy in 10 ms. Estimate the acceleration of the front surface of the bag as it expands. Express your answer in terms of the acceleration of gravity *g*.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: An air bag expands outward with constant positive acceleration. | |
|  | **Strategy:** Assume the air bag has a thickness of 1 ft or about 0.3 m. It must expand that distance within the given time of 10 ms. Employ the relationship between acceleration, displacement, and time (Equation 2-11) to find the acceleration. | |
|  | **Solution:** Solve Equation 2-11 for *a*: |  |
|  | **Insight:** The very large acceleration of an expanding airbag can cause severe injury to a small child whose head is too close to the bag when it deploys. Children are safest in the back seat! | |

**128.** **IP** Coasting due west on your bicycle at 8.4 m/s, you encounter a sandy patch of road 7.2 m across. When you leave the sandy patch your speed has been reduced by 2.0 m/s to 6.4 m/s. **(a)** Assuming the sand causes a constant acceleration, what was the bicycle’s acceleration in the sandy patch? Give both magnitude and direction. **(b)** How long did it take to cross the sandy patch? **(c)** Suppose you enter the sandy patch with a speed of only 5.4 m/s. Is your final speed in this case 3.4 m/s, more than 3.4 m/s, or less than 3.4 m/s? Explain.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: A bicycle travels in a straight line, slowing down at a uniform rate as it crosses the sandy patch. | |
|  | **Strategy:** Use the time-free relationship between displacement, velocity, and acceleration (Equation 2-12) to find the acceleration. The time can then be determined from the average velocity and the distance across the sandy patch. | |
|  | **Solution: 1. (a)** Calculate the acceleration: | where the negative sign means 2.1 m/s2 to the east. |
|  | **2. (b)**  Solve Equation 2-10 for *t*: |  |
|  | **3. (c)** Examining  (Equation 2-12) in detail, we note that the acceleration is negative, and that the final velocity is the square root of the difference between  and . Because  is constant because the sandy patch doesn’t change, it now represents a larger fraction of the smaller , and the final velocity *v* will be more than  2.0 m/s different than . We therefore expect a final speed of less than 3.4 m/s. | |
|  | **Insight:** In fact, if you try to calculate *v* in part (c) with Equation 2-12 you end up with the square root of a negative number, because the bicycle will come to rest in a distance , less than the 7.2 m length of the sandy patch. | |

**129.** In a physics lab, students measure the time it takes a small cart to slide a distance of 1.00 m on a smooth track inclined at an angle above the horizontal. Their results are given in the following table.

|  |  |  |  |
| --- | --- | --- | --- |
| *θ* | **10.0°** | **20.0°** | **30.0°** |
| time, s | 1.08 | 0.770 | 0.640 |

**(a)** Find the magnitude of the cart’s acceleration for each angle.   
**(b)** Show that your results for part (a) are in close agreement with the formula, *a* = *g* sin *θ*. (We will derive this formula in Chapter 5.)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Picture the Problem**: The cart slides down the inclined track, each time traveling a distance of 1.00 m along the track. | | 1.00 m  ** | |
|  | **Strategy:** The distance traveled by the cart is given by the constant-acceleration equation of motion for position as a function of time (Equation 2-11), where . The magnitude of the acceleration can thus be determined from the given distance | |
|  | traveled and the time elapsed in each case. We can then make the comparison with . | | | |
|  | **Solution: 1.** Find the acceleration from Equation 2-11: |  | |  |
|  | **2.** Now find the values for ** = 10.0°: |  | |  |
|  | **3.** Now find the values for ** = 20.0°: |  | |  |
|  | **4.** Now find the values for ** = 30.0°: |  | |  |
|  | **Insight:** We see very good agreement between the formula  and the measured acceleration. The experimental accuracy gets more and more difficult to control as the angle gets bigger because the elapsed times become very small and more difficult to measure accurately. For this reason Galileo’s experimental approach (rolling balls down an incline with a small angle) gave him an opportunity to make accurate observations about free fall without fancy electronic equipment. | | | |

**130.** Legend has it that Isaac Newton was hit on the head by a falling apple, thus triggering his thoughts on gravity. Assuming the story to be true, estimate the speed of the apple when it struck Newton.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: An apple falls straight downward under the influence of gravity. | |
|  | **Strategy:** The distance of the fall is estimated to be about 3.0 m (about 10 ft). Then use the time-free equation of motion (Equation 2-12) to estimate the speed of the apple. | |
|  | **Solution: 1.** Solve Equation 2-12 for *v*, assuming the apple drops from rest (): |  |
|  | **2.** Let *a* = *g* and calculate *v*: |  |
|  | **Insight:** Newton supposedly then reasoned that the same force that made the apple fall also keeps the Moon in orbit around the Earth, leading to his universal law of gravity (Chapter 12). One lesson we might learn here is—wear a helmet when sitting under an apple tree! | |

**131.** **Jordan’s Jump** Michael Jordan’s vertical leap is reported to be 48 inches. What is his takeoff speed? Give your answer in meters per second.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: Michael Jordan jumps vertically, the acceleration of gravity slowing him down and bringing him momentarily to rest at the peak of his flight. | |
|  | **Strategy:** Because the height of the leap is known, use the time-free equation of motion (Equation 2-12) to find the takeoff speed. | |
|  | **Solution:** Solve Eq. 2-12 for : |  |
|  | **Insight:** That speed is about half of what champion sprinters achieve in the horizontal direction, but is very good among athletes for a vertical leap. High jumpers can jump even higher, but use the running start to their advantage. | |

**132.** Bill steps off a 3.0-m-high diving board and drops to the water below. At the same time, Ted jumps upward with a speed of 4.2 m/s from a 1.0-m-high diving board. Choosing the origin to be at the water’s surface, and upward to be the positive *x* direction, write *x*-versus-*t* equations of motion for both Bill and Ted.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: Two divers move vertically under the influence of gravity. | |
|  | **Strategy:** In both cases we wish to write the equation of motion for position as a function of time and acceleration (Equation 2-11). In Bill’s case, the initial height but the initial velocity is zero because he steps off the diving board. In Ted’s case the initial height  and the initial velocity is +4.2 m/s. In both cases the acceleration is −9.81 m/s2. | |
|  | **Solution: 1.** Equation 2-11 for Bill: |  |
|  | **2.** Equation 2-11 for Ted: |  |
|  | **Insight:** The different initial velocities result in significantly different trajectories for Bill and Ted. | |

**133.** Repeat the previous problem, this time with the origin 3.0 m above the water, and with downward as the positive   
*x* direction.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: Two divers move vertically under the influence of gravity. | |
|  | **Strategy:** In both cases we wish to write the equation of motion for position as a function of time and acceleration (Equation 2-11). Here we’ll take the origin to be at the level of Bill’s board above the water, Ted’s diving board to be at +2.0 m, and the water surface at +3.0 m. Downward is the positive direction so that the acceleration is 9.81 m/s2. In Bill’s case, the initial height  and his initial velocity is zero because he steps off the diving board. In Ted’s case the initial height is  and the initial velocity is  (upward). | |
|  | **Solution: 1.** Equation 2-11 for Bill: |  |
|  | **2.** Equation 2-11 for Ted: |  |
|  | **Insight:** The different initial velocities result in significantly different trajectories for Bill and Ted. | |

**134.** **IP** Standing side by side, you and a friend step off a bridge at different times and fall for 1.6 s to the water below. Your friend goes first, and you follow after she has dropped a distance of 2.0 m. **(a)** When your friend hits the water, is the separation between the two of you 2.0 m, less than 2.0 m, or more than 2.0 m? **(b)** Verify your answer to part (a) with a calculation.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: You and your friend both accelerate from rest straight downward, but at different times. You step off the bridge when your friend has fallen 2.0 m, and your friend hits the water while you are still in the air. | | water  bridge  *t* = 1.6 s  2.0 m  you jump  friend lands  S ? |
|  | **Strategy:** First find the time it takes for your friend to fall  2.0 m using the equation of motion for position as a function of time and acceleration (Equation 2-11). Subtract that time from 1.6 s to find the time elapsed between when you jump and when your friend hits the water. Use Equation 2-11 and the times found above to find the positions of you and your friend at the time your friend lands. Then determine the separation between the known positions. | |
|  | **Solution: 1. (a)** Because your friend has a greater average speed than you do during the time between when you jump and your friend lands, the separation between the two of you will increase to a value more than 2.0 m. | | |
|  | **2. (b)** Find the time it takes to fall 2.0 m from Equation 2-11 with : |  | |
|  | **3.** Find the distance your friend fell in 1.6 s: |  | |
|  | **4.** Find the distance you fell in the shorter time: |  | |
|  | **5.** Find the difference in your positions: |  | |
|  | **Insight:** Because of her head start, your friend will always have a higher average velocity than you, and the separation between you and her will continue to increase the longer you both fall. | | |

**135.** In a well-known Jules Verne novel, Phileas Fogg travels around the world in 80 days. What was Mr. Fogg’s approximate average speed during his adventure?

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: Phileas Fogg travels in a straight line all the way around the world. | |
|  | **Strategy:** The average speed is the distance divided by elapsed time. We will estimate that Mr. Fogg travels a distance equal to the equatorial circumference of the Earth. This is an approximation, because his path was most likely much more complicated than that, but we were asked only for the approximate speed. | |
|  | **Solution:** Find the circumference of the Earth: |  |
|  | Divide the distance by the time: |  |
|  | **Insight:** This speed corresponds to about 13 mi/h and is faster than humans can walk. Giving time for sleeping, eating, and other delays, Mr. Fogg needs a relatively fast means of travel. | |

**136.** You jump from the top of a boulder to the ground 1.5 m below. Estimate your deceleration on landing.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: You jump off a boulder, accelerate from rest straight downward and land, bending your knees so that your center of mass comes to rest over a short vertical distance. | |
|  | **Strategy:** Employ the relationship between acceleration, displacement, and velocity (Equation 2-12) to find your final velocity just before landing. Then estimate the distance your center of mass will move after your feet contact the ground, and use that distance to estimate your deceleration rate. | |
|  | **Solution: 1.** Solve Equation 2-12 for velocity *v*: |  |
|  | **2.** Estimate your center of mass moves downward about 0.5 m after your feet contact the ground and you bend your knees into a crouching position. Solve Equation 2-12 for acceleration: |  |
|  | **Insight:** When a gymnast lands from an even higher altitude, she might try to bend her knees even less in order to impress the judges. If she lands from an altitude of 3.0 m and bends her knees so her center of mass moves only 0.2 m, her acceleration is −15*g*! | |

**137.** **CE** At the edge of a roof you drop ball A from rest, and then throw ball B downward with an initial velocity of  Is the increase in speed just before the balls land more for ball A, more for ball B, or the same for each ball?



|  |  |
| --- | --- |
|  | **Picture the Problem**: Two balls are released from the edge of a roof. Ball A is dropped from rest but ball B is thrown downward with an initial velocity |
|  | **Strategy:** Use the definition of acceleration to answer the conceptual question, keeping in mind the average speed of ball B is greater than the average speed of ball A. |
|  | **Solution:** The two balls fall the same distance but ball B has the greater average speed and falls for a shorter length of time. Because each ball accelerates at the same rate of 9.81 m/s2, ball A accelerates for a longer time and the increase in speed is more for ball A than it is for ball B. |
|  | **Insight:** If ball B were fired downward at an extremely high speed, it would reach the ground within a very short interval of time and its speed would hardly change at all. |

**138.** **IP** A youngster bounces straight up and down on a trampoline. Suppose she doubles her initial speed from 2.0 m/s to 4.0 m/s. **(a)** By what factor does her time in the air increase? **(b)** By what factor does her maximum height increase?   
**(c)** Verify your answers to parts (a) and (b) with an explicit calculation.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: A youngster bounces straight up and down on a trampoline. The child rises straight upward, slows down, and momentarily comes to rest before falling straight downward again. | |
|  | **Strategy:** Find the time of flight by exploiting the symmetry of the situation. If it takes time *t* for gravity to slow the child down from her initial speed *v*0 to zero, it will take the same amount of time to accelerate her back to the same speed. She therefore lands at the same speed *v*0 with which she took off. Use this fact together with Equation 2-7 to find the time of flight. The maximum height she achieves is related to the square of *v*0, as indicated by Equation 2-12. | |
|  | **Solution: 1. (a)** Because the time of flight depends linearly upon the initial velocity, doubling *v*0 will increase her time of flight by a factor of 2. | |
|  | **2. (b)** Because the time of flight depends upon the square of the initial velocity, doubling *v*0 will increase her maximum altitude by a factor of 4. | |
|  | **3. (c)** The time of flight for , using Eq. 2-7: |  |
|  | **4.** The time of flight for : |  |
|  | **5.** The maximum height for , using Eq. 2-12: |  |
|  | **6.** The maximum height for : |  |
|  | **Insight:** The reason the answer in step 6 is not exactly four times larger than the answer in step 5 is due to the rounding required by the fact that there are only two significant digits. If you recalculate using 2.00 m/s and 4.00 m/s, the answers are 0.204 and 0.816 m, respectively. | |

**139.** **IP** A popular entertainment at some carnivals is the blanket toss (see photo, p. 39). **(a)** If a person is thrown to a maximum height of 28.0 ft above the blanket, how long does she spend in the air? **(b)** Is the amount of time the   
person is above a height of 14.0 ft more than, less than, or equal to the amount of time the person is below a height   
of 14.0 ft? Explain. **(c)** Verify your answer to part (b) with a calculation.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: The person is thrown straight upward, slows down, and momentarily comes to rest before falling straight downward again. | |
|  | **Strategy:** Find the time of flight by exploiting the symmetry of the situation. If it takes time *t* for gravity to slow the person down from her initial speed *v*0 to zero, it will take the same amount of time to accelerate her back to the same speed. It therefore takes the same amount of time for her to rise to the peak of her flight than it does for her to return to the blanket. Use this fact together with Equation 2-11 with *v*0 = 0 (corresponding to the second half of her flight, from the peak back down to the blanket) to find the time of flight. The time above and below 14.0 ft can be found using the same equation. | |
|  | **Solution: 1. (a)** The time of flight  can be found from Equation 2-11: |  |
|  | **2. (b)** The person’s average speed is less during the upper half of her trajectory, so the time she spends in that portion of her flight is more than the time she spends in the lower half of her flight. | |
|  |  | |
|  | **3. (c)** The time she spends above 14.0 ft  is the same time of her flight if her  maximum height were 14.0 ft: |  |
|  | **4.** The time spent below 14.0 ft is the  remaining portion of the total time of flight: |  |
|  | **Insight:** The symmetry of the motion of a freely falling object can often be a useful tool for solving problems quickly. | |

**140.** Referring to Conceptual Checkpoint 2–5, find the separation between the rocks at **(a)** *t* = 1.0 s, **(b)** *t* = 2.0 s, and   
**(c)** *t* = 3.0 s,where time is measured from the instant the second rock is dropped. **(d)** Verify that the separation   
increases linearly with time.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: The two rocks fall straight downward along a similar path except at different times. | |  |
|  | **Strategy:** First find the time elapsed between the release of the two rocks by finding the time required for the first rock to fall 4.00 m, using the equation of motion for position as a function of time and acceleration (Equation 2-11). The positions as a function of time for each rock can then be compared to find a separation distance as a function of time. | |
|  | **Solution: 1. (a)** Find the time required for rock A to fall 4.00 m: |  |
|  | **2.** Let *t* represent the time elapsed from the instant rock B is dropped. The position of rock A (Equation 2-11) is thus: |  |
|  | **4.** The position of rock B (Equation 2-11) is: |  | |
|  | **5.** Find the separation between the rocks: |  | |
|  | **6.** Find  for *t* = 1.0 s: |  | |
|  | **7.** **(b)** Find  for *t* = 2.0 s: |  | |
|  | **8.** **(c)** Find  for *t* = 1.0 s: |  | |
|  | **9. (d)** The linear dependence of  upon *t* can be verified by examining the equation derived in step 5. | | |
|  | **Insight:** The only way for rock B to catch up to rock A would be for rock B to be thrown downward with a large initial speed. In that case the separation becomes  which decreases to zero as long as  is greater than 8.86 m/s. | | |

**141.** In the previous problem, what is the minimum initial speed of the camera if it is to just reach the passenger?   
(*Hint:* When the camera is thrown with its minimum speed, its speed on reaching the passenger is the same   
as the speed of the passenger.)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: The trajectories of the balloon and camera are shown at right. The balloon rises at a steady rate while the camera’s speed is continually slowing down under the influence of gravity. The camera is caught when the two trajectories meet. | |  |
|  | **Strategy:** The camera meets the balloon when the positions are equal, so that is our starting point. For the case when the camera just barely meets the balloon, the velocity of the camera must match the velocity of the balloon (2.0 m/s). We use this fact to find the time the two must meet, and substitute that into the position equation. We can then solve for the initial velocity of the camera. | |
|  | **Solution: 1.** Write Equation 2-10 for the balloon: |  | |
|  | **2.** Write Equation 2-12 for the camera: |  | |
|  | **3.** Set  and solve for : |  | |
|  | **4.** As indicated above, the camera will be caught not only when it’s at the same position as the balloon, but when its velocity is the same as well, so set |  | |
|  | **5.** The two will meet at a time when their velocities are equal. Write Equation 2-7 for the camera and set its final velocity equal to the balloon’s velocity, and find the time. |  | |
|  | **6.** Substitute the time into the equation in step 4: |  | |
|  | **7.** You can get the roots using the quadratic formula, but you might recognize the simple factors here. Only the positive root corresponds to the camera going *upward*: |  | |
|  | **Insight:** This is a complicated problem that always ends with a quadratic solution. It required the kind of strategy that must usually be mapped out after trying a few things; don’t feel bad if you didn’t intuitively choose this strategy. There are other strategies that work, but they are equally complicated. | | |

**142.** **Old Faithful** Watching Old Faithful erupt, you notice that it takes a time *t* for water to emerge from the base of the geyser and reach its maximum height. **(a)** What is the height of the geyser, and **(b)** what is the initial speed of the water? Evaluate your expressions for **(c)** the height and **(d)** the initial speed for a measured time of 1.65 s.

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: The water shoots straight upward, slows down, and momentarily comes to rest before falling straight downward again. | |
|  | **Strategy:** Find the height of the geyser by exploiting the symmetry of the situation. If it takes time *t* for gravity to slow the water down from its initial speed *v*0 to zero, it will take the same amount of time to accelerate it back to the same speed. The height of the geyser is therefore determined by the distance the water will fall from rest in time *t* (Equation 2-11). Gravity will slow the water down from its initial velocity to zero in time *t* at a known rate (), so that fact can be used to find the initial velocity (Equation 2-7). | |
|  | **Solution: 1. (a)** Solve Equation 2-11 for *x*0, setting   and  for the case when the water falls from rest in time *t*: |  |
|  | **2. (b)** Use Equation 2-7 to find the initial velocity if the final  velocity is zero (upward portion of the flight): |  |
|  | **3. (c)** Substitute *t* = 1.65 s into the equation from step 1: |  |
|  | **4. (d)** Substitute *t* = 1.65 s into the equation from step 2: |  |
|  | **Insight:** If you round off *g* = 10 m/s2, you can impress your friends by memorizing these simple formulae and doing the quick calculations in your head! | |

**143.** **IP** A ball is thrown upward with an initial speed  When it reaches the top of its flight, at a height *h*, a second ball is thrown upward with the same initial velocity. **(a)** Sketch an *x*-versus-*t* plot for each ball. **(b)** From your graph, decide whether the balls cross paths at *h*/2, above *h*/2, or below *h*/2. **(c)** Find the height where the paths cross.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: The trajectories of the two balls are shown at right. Remember that in each case the balls are traveling straight up and straight down; the graphs look parabolic because time is the *x* axis. Ball B is tossed upward at the instant ball A reaches the peak of its flight. Ball A has begun its descent when it is passed by ball B, which is still on its way up toward its peak. | |  |
|  | **Strategy:** The positions are equal to each other when the balls cross paths. The launch times are offset by the time it takes the ball to reach the peak of its flight. That time is given by the time it takes gravity to slow the ball from *v*0 down to zero (Equation 2-7). The time the balls cross is directly between the time ball B is launched and ball A lands. Once we have the time figured out we can find the position of ball A in terms of its maximum height *h*. | |
|  | **Solution: 1.** The plot of *x*-*versus-t* for the two balls is shown above. | | |
|  | **2.** Judging from the plot the balls will cross paths above *h* / 2. | | |
|  | **3.** Find the time it takes ball A to reach its peak: |  | |
|  | **4.** Because ball B is launched at time  and ball A lands at time , the two balls will cross at a time midway between these, or at time . | | |
|  | **5.** Find the position of ball A at time *t*cross using Eq. 2-11: |  | |
|  | **6.** Find the maximum height *h* using Equation 2-12: |  | |
|  | **7.** Now write  in terms of *h*: |  | |
|  | **Insight:** The balls do not cross right at *h* / 2 because they spend more time above *h* / 2 than they do below, because their average speeds are smaller during the top half of their flight. | | |

**144.** Weights are tied to each end of a 20.0-cm string. You hold one weight in your hand and let the other hang vertically a height *h* above the floor. When you release the weight in your hand, the two weights strike the ground one after the other with audible thuds. Find the value of *h* for which the time between release and the first thud is equal to the time between the first thud and the second thud.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: The two weights fall straight downward from rest along a similar path except at different times. | | *h*  20 cm |
|  | **Strategy:** The problem requires that the time to fall a distance *h* from rest (the time between release and the first thud) is the time to fall a distance *h* + 20 cm (second thud) minus the time to fall a distance *h* (first thud). We can set these times equal to each other, use Equation 2-11 to write the times in terms of heights, and then solve for *h*. | |
|  | **Solution: 1.** Set the time  intervals equal to each other: |  |
|  | **2.** Now use Equation 2-11 to write  the times in terms of the heights: |  | |
|  | **3.** Square both sides and multiply by *g* / 2: |  | |
|  | **Insight:** The tension in the string will be zero during the descent because each ball accelerates at the same rate. Therefore the string will have no effect upon the motion of the balls. | | |

**145.** A stalactite on the roof of a cave drips water at a steady rate to a pool 4.0 m below. As one drop of water hits the pool, a second drop is in the air, and a third is just detaching from the stalactite. **(a)** What are the position and velocity of the second drop when the first drop hits the pool? **(b)** How many drops per minute fall into the pool?

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: The three drops are positioned as depicted at right. They all fall straight downward from an initial height of 4.0 m. | | 4.0 m  *x*2  stalactite  1  2  3 |
|  | **Strategy:** The time interval between drops is half the time it takes a drop to fall the entire 4.0 m. Use this fact to find the position and velocity of drop 2 when drop 1 hits the pool (equations 2-11 and 2-7). Then the time interval between drops can be used to find the number of drops per minute. | |
|  | **Solution: 1. (a)** Find the time interval between  drops, using Equation 2-11 to find the fall time: |  |
|  | **2.** Now use Equation 2-11 to find the position  of drop 2: |  |
|  | **3.** Use Equation 2-7 to find the speed of drop 2: |  | |
|  | **4.** **(b)** Find the drop rate from the time interval: |  | |
|  | **Insight:** Note that it takes half the drop time to fall the first quarter of the drop distance, and half the time to fall the final three quarters of the distance. | | |

**146.** Suppose the first rock in Conceptual Checkpoint 2–5 drops through a height *h* before the second rock is released from rest. Show that the separation between the rocks, *S*, is given by the following expression:



In this result, the time *t* is measured from the time the second rock is dropped.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Picture the Problem**: The two rocks fall straight downward along a similar path except at different times. | |  |
|  | **Strategy:** First find the time elapsed between the release of the two rocks by finding the time required for the first rock to fall a distance *h*, using the equation of motion for position as a function of time and acceleration (Equation 2-11). The positions as a function of time for each rock can then be compared to find a separation distance as a function of time. | |
|  | **Solution: 1. (a)** Find the time required for rock A to  fall a distance *h*: |  |
|  | **2.** Let *t* represent the time elapsed from the instant  rock B is dropped. The position of rock A (equation  2-11) is thus: |  | |
|  | **3.** The position of rock B (Equation 2-11) is: |  | |
|  | **4.** Find the separation between the rocks: |  | |
|  | **Insight:** The separation between the two rocks increases linearly with time *t*. | | |

**147.** An arrow is fired with a speed of 20.0 m/s at a block of Styrofoam resting on a smooth surface. The arrow penetrates a certain distance into the block before coming to rest relative to it. During this process the arrow’s deceleration has a magnitude of 1550 m/s2 and the block’s acceleration has a magnitude of 450 m/s2. **(a)** How long does it take for the arrow to stop moving with respect to the block? **(b)** What is the common speed of the arrow and block when this happens? **(c)** How far into the block does the arrow penetrate?

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: An arrow travels horizontally at 20.0 m/s and impacts the Styrofoam. It continues to travel in the positive direction, but more slowly due to its collision with the Styrofoam. The arrow and the Styrofoam then move together at the same speed in the positive direction. | |
|  | **Strategy:** Find the final velocity of the block in terms of the collision time  by using Equation 2-7. Because this is also the final velocity of the arrow, the collision time  can be determined by using the known accelerations and the initial velocity of the arrow. The final velocity and penetration depth traveled can then be found from applying equations 2-7 and 2-11. | |
|  | **Solution: 1. (a)** Set the final velocities of the arrow and the block equal to each other and apply Equation 2-7 to find |  |
|  | **2.** **(b)** Now apply Equation 2-7 to find : |  |
|  | **3.** **(c)** The penetration distance is a bit tricky because both the arrow and the block move while they are colliding. The penetration distance is the difference between how far the arrow moves and how far the block moves during the collision time interval. |  |
|  | **Insight:** We could also analyze this collision using the concept of momentum conservation (Chapter 9) and work and energy (Chapter 7). | |

**148.** Sitting in a second-story apartment, a physicist notices a ball moving straight upward just outside her window. The ball is visible for 0.25 s as it moves a distance of 1.05 m from the bottom to the top of the window. **(a)** How long does it take before the ball reappears? **(b)** What is the greatest height of the ball above the top of the window?

|  |  |  |
| --- | --- | --- |
|  | **Picture the Problem**: This exercise considers a generic object traveling in a straight line with constant acceleration. | |
|  | **Strategy:** Manipulate the suggested equations with algebra to derive the desired results. | |
|  | **Solution: 1. (a)** Begin with Equation 2-12: |  |
|  | **2.** Set *x* = 0 and solve for *v*: |  |
|  | **3.** **(b)** First write Equation 2-7 and  substitute for *v*. Then solve for *t*: |  |
|  | **4. (c)** Write Equation 2-11 as given and  apply the quadratic formula to solve for *t*: |  |
|  | **Insight:** When an object undergoes uniform acceleration its position is a quadratic function of time. The quadratic formula is therefore an appropriate one to describe the motion of the object. | |