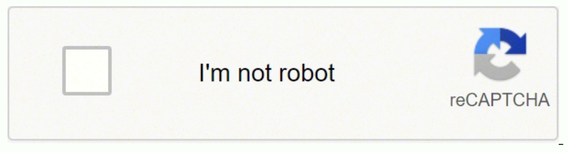

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We must also find the components of these variables along the x- and y-axes. As an object travels through the air, it encounters a frictional force that slows its motion called air resistance. This equation yields two solutions t = 3.96 and t = –1.03. The expression we found for y y while solving part (a) of the previous problem works for any projectile motion problem where air resistance is negligible. Now we must find v 0y v 0y , the component of the initial velocity in the y-direction. Make a game out of this simulation by trying to hit the target. Figure 5.31 The diagram shows the projectile motion of a large rock from a volcano. If an object is thrown horizontally, travels with an average x-component of its velocity equal to 5\,\text{m/s}, and does not hit the ground, what will be the x-component of the displacement after 20\,\text{s}? (a) Calculate the height at which the shell explodes. Call the maximum height y=h y=h ; then, h= v 0y 2 2g . Because y 0 y 0 is zero, this equation reduces to y= 1 2 (v 0y + v y)t . The most important concept in projectile motion is that horizontal and vertical motions are independent, meaning that they don’t influence one another. Ask students to guess what the motion of a projectile might depend on? [BL][OL] Review addition of vectors graphically and analytically. Assume the ground is uniformly level. Demonstrate the path of a projectile by doing a simple demonstration. Horizontal Motion(a x =0) x= x 0 + v x t v x = v 0x = v x =velocity is a constant. Breaking this two-dimensional motion into two independent one-dimensional motions will allow us to solve for the time. Therefore, t = 2y (v 0y + v y) = 2(233 m) (67.6 m/s) = 6.90 s. The magnitudes of these vectors are x and y, as illustrated in Figure 5.28. It also reviews basic trigonometry for finding the sine, cosine and tangent of an angle. Both accelerations are constant, so we can use the kinematic equations. The maximum height depends only on the vertical component of the initial velocity. The horizontal displacement is horizontal velocity multiplied by time as given by x= x 0 + v x t x= x 0 + v x t , where x 0 x 0 is equal to zerowhere v x v x is the x-component of the velocity, which is given by v x = v 0 cos θ 0 . Recombine the two motions to find the total displacement s s and velocity v v . Rearranging terms gives a quadratic equation in t t (4.90 m/s 2) t 2 −(14.3 m/s)t−(20.0 m)=0 . Since we know the initial velocity, initial position, and the value of vy when the firework reaches its maximum height, we use the following equation to find y y v y 2 = v 0y 2 −2g(y− y 0). Toss a dark beanbag in front of a white board so that students can get a good look at the projectile path. For review, the kinematic equations from a previous chapter are summarized in Table 5.1. x= x 0 + v avg t x= x 0 + v avg t (when a=constant a=constant) v avg = v 0 +v 2 v avg = v 0 +v 2 (when a=0 a=0) v= v 0 +at v= v 0 +at x= x 0 + v 0 t+ 1 2 a t 2 x= x 0 + v 0 t+ 1 2 a t 2 v 2 = v 0 2 +2a(x− x 0) v 2 = v 0 2 +2a(x− x 0) Table 5.1 Summary of Kinematic Equations (constant a) Where x is position, x0 is initial position, v is velocity, vavg is average velocity, t is time and a is acceleration. Initial values are denoted with a subscript 0. This time is also reasonable for large fireworks. Projectile motion is the motion of an object projected into the air and moving under the influence of gravity. The time to reach the ground would be halved since the horizontal component of the velocity is doubled. Figure 5.27 The diagram shows the projectile motion of a cannonball shot at a horizontal angle versus one dropped with no horizontal velocity. Because y 0 y 0 and v y v y are both zero, the equation simplifies to 0= v 0y 2 −2gy. y= 1 2 (v 0y + v y)t . Note that the final vertical velocity, v y v y , at the highest point is zero. (d) The x- and y-motions are recombined to give the total velocity at any given point on the trajectory. The time t t for both motions is the same, and so x x is x=(18.1 m/s)(6.90 s)=125 m. To do this, we separate projectile motion into the two components of its motion, one along the horizontal axis and the other along the vertical. (4.90 m/s 2) t 2 −(14.3 m/s)t−(20.0 m)=0 . The time to reach the ground would remain the same since the vertical component of the velocity also gets doubled. y= v 0y 2 2g . Replay this in slow motion to observe and compare the altitudes and trajectories. For notation, d is the total displacement, and x and y are its components along the horizontal and vertical axes. (b) How much time passed between the launch of the shell and the explosion? Figure 5.28 A boy kicks a ball at angle θ, and it is displaced a distance of s along its trajectory. (c) What is the horizontal displacement of the shell when it explodes? [BL][OL][AL] Talk about the sample problem. Projectile motion is the motion of an object projected vertically upward into the air and moving under the influence of gravity. Another way of finding the time is by using y= y 0 + v 0y t− 1 2 g t 2 y= y 0 + v 0y t− 1 2 g t 2 , and solving the quadratic equation for t t . (a) The greater the initial speed v 0 v 0 , the greater the range for a given initial angle. The fuse is timed to ignite the shell just as it reaches its highest point above the ground. Since vertical and horizontal motions are independent, we can analyze them separately, along perpendicular axes. Review kinematic equations. The problem solving procedures here are the same as for one-dimensional kinematics. Note that the only common variable between the motions is time t t . {-100}\,\text{m} {-4}\,\text{m} 4\,\text{m} 100\,\text{m} 12. By height we mean the altitude or vertical position y y above the starting point. The initial angle θ 0 θ 0 also has a dramatic effect on the range. We can find the time for this by using y= y 0 + v 0y t− 1 2 g t 2 . Because gravity is vertical, ax = 0. Solving for y y gives y= v 0y 2 2g . During a fireworks display like the one illustrated in Figure 5.30, a shell is shot into the air with an initial speed of 70.0 m/s at an angle of 75° above the horizontal. v x = v 0 cos θ 0 =(70.0 m/s)(cos 75 ∘)=18.1 m/s. −20.0 m=(14.3 m/s)t−(4.90 m/s 2) t 2 . What is projectile motion? (b) The effect of initial angle θ 0 θ 0 on the range of a projectile with a given initial speed. Vertical motion (assuming positive is up a y =−g=−9.80 m/s 2 a y =−g=−9.80 m/s 2) y = y 0 + 1 2 (v 0y + v y)t v y = v 0y −gt y = y 0 + v 0y t− 1 2 g t 2 v y 2 = v 0y 2 −2g(y− y 0) y = y 0 + 1 2 (v 0y + v y)t v y = v 0y −gt y = y 0 + v 0y t− 1 2 g t 2 v y 2 = v 0y 2 −2g(y− y 0) Solve for the unknowns in the two separate motions (one horizontal and one vertical). While the rock is in the air, it rises and then falls to a final position 20.0 m lower than its starting altitude. The following steps are used to analyze projectile motion: Separate the motion into horizontal and vertical components along the x- and y-axes. (c) The velocity in the vertical direction begins to decrease as the object rises; at its highest point, the vertical velocity is zero. Figure 5.32 Trajectories of projectiles on level ground. You can see that the cannonball in free fall falls at the same rate as the cannonball in projectile motion. There is more than one way to solve for the time to the highest point. It is important to note that the range doesn’t apply to problems where the initial and final y position are different, or to cases where the object is launched perfectly horizontally. Note that both cannonballs have the same vertical position over time. 11. Therefore, The time for projectile motion is completely determined by the vertical motion. Note that any combination of trajectories that add to 90 degrees will have the same range in the absence of air resistance, although the maximum heights of those paths are different. The highest point in any trajectory, the maximum height, is reached when v y =0 v y =0 ; this is the moment when the vertical velocity switches from positive (upwards) to negative (downwards). The horizontal motion is a constant velocity in the absence of air resistance. This expression is a quadratic equation of the form a t 2 +bt+c=0 a t 2 +bt+c=0 , where the constants are a = 4.90, b = –14.3, and c = –20.0. Its solutions are given by the quadratic formula t= −b± b 2 −4ac 2a . So any projectile that has an initial vertical velocity of 14.3m/s 14.3m/s and lands 20.0 m below its starting altitude will spend 3.96 s in the air. y=−20.0 m. This video presents an example of finding the displacement (or range) of a projectile launched at an angle. Figure 5.30 The diagram shows the trajectory of a fireworks shell. Is the initial velocity important? (a) Calculate the time it takes the rock to follow this path. Keep in mind that if the cannon launched the ball with any vertical component to the velocity, the vertical displacements would not line up perfectly. Projectile motion is the motion of an object projected into the air and moving independently of gravity. Projectile motion is the motion of an object projected horizontally into the air and moving independently of gravity. Treat the motion as two independent one-dimensional motions, one horizontal and the other vertical. 0= v 0y 2 −2gy. Experiment with changing the angle, initial speed, and mass, and adding in air resistance. If we take the initial position y 0 y 0 to be zero, then the final position is y=−20.0 m. The magnitudes of the displacement s s along x- and y-axes are called x x and y. When air resistance is negligible, the range R R of a projectile on level ground is R= v 0 2 sin2 θ 0 g , R= v 0 2 sin2 θ 0 g , where v 0 v 0 is the initial speed and θ 0 θ 0 is the initial angle relative to the horizontal. Now the initial vertical velocity is the vertical component of the initial velocity, found from v 0 y = v 0 sin θ 0 =(25.0 m/s)(sin 35 ∘)=14.3 m/s. The time a projectile is in the air depends only on its vertical motion. Draw a reference grid on the whiteboard, then toss the bag at different angles while taking a video. Figure 5.27 compares a cannonball in free fall (in blue) to a cannonball launched horizontally in projectile motion (in red). We can then define x 0 x 0 and y 0 y 0 to be zero and solve for the maximum height. 14. If a ball is thrown straight up with an initial velocity of 20\,\text{m/s} upward, what is the maximum height it will reach? Thus, v 0y = v 0 sin θ 0 =(70.0 m/s)(sin 75 ∘)=67.6 m/s v 0y = v 0 sin θ 0 =(70.0 m/s)(sin 75 ∘)=67.6 m/s and y y is y= (67.6 m/s) 2 2(9.80 m/s 2), y= (67.6 m/s) 2 2(9.80 m/s 2), as in projectile motion. Since up is positive, the initial velocity and maximum height are positive, but the acceleration due to gravity is negative. Now, v x = v 0 cos θ 0 =(70.0 m/s)(cos 75 ∘)=18.1 m/s. Suppose a large rock is ejected from a volcano, as illustrated in Figure 5.31, with a speed of 25.0 m/s 25.0 m/s and at an angle 35° 35° above the horizontal. t = 2y (v 0y + v y) = 2(233 m) (67.6 m/s) = 6.90 s. Discuss the variables or unknowns in each part of the problem Ask students which kinematic equations may be best suited to solve the different parts of the problem. What is the force experienced by a projectile after the initial force that launched it into the air in the absence of air resistance? In this simulation you will learn about projectile motion by blasting objects out of a cannon. Note that this definition defines the upwards direction as positive. The kinematic equations for horizontal and vertical motion take the following forms Horizontal Motion(a x =0) x= x 0 + v x t v x = v 0x = v x =velocity is a constant. The numbers in this example are reasonable for large fireworks displays, the shells of which do reach such heights before exploding. Click to view content 13. The student knows and applies the laws governing motion in a variety of situations. y= y 0 + v 0y t− 1 2 g t 2 . h= v 0y 2 2g . The first step is to choose an initial position for x x and y y . It is given by v 0y = v 0 sinθ v 0y = v 0 sinθ , where v 0y v 0y is the initial velocity of 70.0 m/s, and θ= 75 ∘ θ= 75 ∘ is the initial angle. x=(18.1 m/s)(6.90 s)=125 m. {-20.4}\,\text{m} {-1.02}\,\text{m} 1.02\,\text{m} 20.4\,\text{m} The fact that vertical and horizontal motions are independent of each other lets us predict the range of a projectile. Usually, it is simplest to set the initial position of the object so that x 0 =0 x 0 =0 and y 0 =0 y 0 =0 . When you are able to see the launch of fireworks, you will notice several seconds pass before the shell explodes. Vary the toss angles, so different paths can be displayed. How will these things affect its height and the distance it covers? v y 2 = v 0y 2 −2g(y− y 0). How does the initial velocity of a projectile affect its range? You can choose between objects such as a tank shell, a golf ball or even a Buick. Once the shell explodes, air resistance has a major effect, and many fragments will land directly below, while some of the fragments may now have a velocity in the –x direction due to the forces of the explosion. In addition, the High School Physics Laboratory Manual addresses content in this section in the lab titled: Motion in Two Dimensions, as well as the following standards: (4) Science concepts. The negative value of time implies an event before the start of motion, so we discard it. The nuclear force The gravitational force The electromagnetic force The contact force Use the Check Your Understanding questions to assess whether students achieve the learning objectives for this section. Displacement d= x 2 + y 2 θ= tan −1 (y/x) Velocity v= v x 2 + v y 2 θ v = tan −1 (v y / v x) Displacement d= x 2 + y 2 θ= tan −1 (y/x) Velocity v= v x 2 + v y 2 θ v = tan −1 (v y / v x) θ θ is the direction of the displacement d d , and θ v θ v is the direction of the velocity v v . [BL][OL][AL] Explain the term projectile motion. The time to reach the ground would be doubled since the horizontal component of the velocity is doubled. The components of acceleration are then very simple ay = –g = –9.80 m/s2. We’ll call the horizontal axis the x-axis and the vertical axis the y-axis. If students are struggling with a specific objective, the Check Your Understanding will help identify which objective is causing the problem and direct students to the relevant content. air resistance maximum height (of a projectile) projectile projectile motion range trajectory Projectile motion is the motion of an object thrown (projected) into the air. The object is called a projectile, and its path is called its trajectory. The motion can be broken into horizontal and vertical motions in which a x =0 a x =0 and a y =g a y =g . This demonstration could be extended by using digital photography. v x = v 0 cos θ 0 . As the object falls towards the Earth again, the vertical velocity increases again in magnitude but points in the opposite direction to the initial vertical velocity. The time to reach the ground would remain the same since the vertical component is unchanged. The range is the horizontal distance R traveled by a projectile on level ground, as illustrated in Figure 5.32. The student is expected to: (C) analyze and describe accelerated motion in two dimensions using equations. Is the angle important? If the horizontal component of a projectile's velocity is doubled, but the vertical component is unchanged, what is the effect on the time of flight? Throughout history, people have been interested in finding the range of projectiles for practical purposes, such as aiming cannons. Introduce the concept of air resistance. y. (See Figure 5.29 Figure 5.29 (a) We analyze two-dimensional projectile motion by breaking it into two independent one-dimensional motions along the vertical and horizontal axes. v 0 y = v 0 sin θ 0 =(25.0 m/s)(sin 35 ∘)=14.3 m/s. The horizontal displacement found here could be useful in keeping the fireworks fragments from falling on spectators. For problems of projectile motion, it is important to set up a coordinate system. Substituting known values yields −20.0 m=(14.3 m/s)t−(4.90 m/s 2) t 2 . We can use the analytical method of vector addition, which uses A= A x 2 + A y 2 A= A x 2 + A y 2 and θ= tan −1 (A y / A x) θ= tan −1 (A y / A x) to find the magnitude and direction of the total displacement and velocity. As usual, we use velocity, acceleration, and displacement to describe motion. The time is t = 3.96 s or –1.03 s. After the initial force that launches the object, it only experiences the force of gravity. The student knows and applies the laws governing motion in a variety of situations. (b) The horizontal motion is simple, because a x =0 a x =0 and v x v x is thus constant. The student is expected to: (C) analyze and describe accelerated motion in two dimensions using equations, including projectile and circular examples. In this case, the easiest method is to use y= y 0 + 1 2 (v 0y + v y)t y= y 0 + 1 2 (v 0y + v y)t . Obviously, the greater the initial speed v 0 v 0 , the greater the range, as shown in the figure above. Because air resistance is negligible, a x =0 a x =0 and the horizontal velocity is constant. t= −b± b 2 −4ac 2a . The rock strikes the side of the volcano at an altitude 20.0 m lower than its starting point. These axes are perpendicular, so A x =Acosθ A x =Acosθ and A y =Asinθ A y =Asinθ are used. This equation defines the maximum height of a projectile. You may verify these solutions as an exercise. The magnitudes of the components of the velocity v v are v x =vcosθ v x =vcosθ and v y =vsinθ v y =vsinθ , where v v is the magnitude of the velocity and θ θ is its direction. Air resistance does significantly alter trajectory motion, but due to the difficulty in calculation, it is ignored in introductory physics. By the end of this section, you will be able to do the following: Describe the properties of projectile motion Apply kinematic equations and vectors to solve problems involving projectile motion The learning objectives in this section will help your students master the following standards: (4) Science concepts.

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