

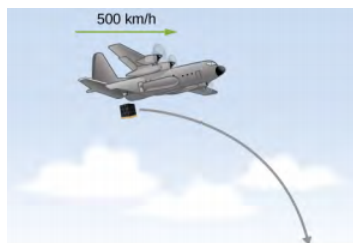
## 17.E: Projectile Motion (Exercises)

### Conceptual Questions

1. Give an example of a trajectory in two or three dimensions caused by independent perpendicular motions.
2. If the instantaneous velocity is zero, what can be said about the slope of the position function?
3. If the position function of a particle is a linear function of time, what can be said about its acceleration?
4. If an object has a constant x-component of the velocity and suddenly experiences an acceleration in the y direction, does the x-component of its velocity change?
5. If an object has a constant x-component of velocity and suddenly experiences an acceleration at an angle of  $70^\circ$  in the x direction, does the x-component of velocity change?
6. Answer the following questions for projectile motion on level ground assuming negligible air resistance, with the initial angle being neither  $0^\circ$  nor  $90^\circ$ : (a) Is the velocity ever zero? (b) When is the velocity a minimum? A maximum? (c) Can the velocity ever be the same as the initial velocity at a time other than at  $t = 0$ ? (d) Can the speed ever be the same as the initial speed at a time other than at  $t = 0$ ?
7. Answer the following questions for projectile motion on level ground assuming negligible air resistance, with the initial angle being neither  $0^\circ$  nor  $90^\circ$ : (a) Is the acceleration ever zero? (b) Is the vector  $\vec{v}$  ever parallel or antiparallel to the vector  $\vec{a}$ ? (c) Is the vector  $\vec{v}$  ever perpendicular to the vector  $\vec{a}$ ? If so, where is this located?

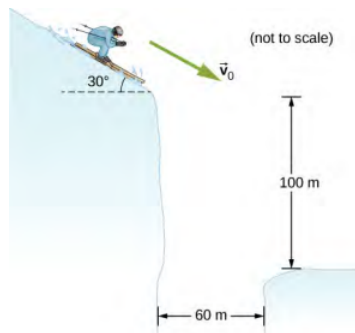
### Problems

8. A bullet is shot horizontally from shoulder height (1.5 m) with an initial speed 200 m/s. (a) How much time elapses before the bullet hits the ground? (b) How far does the bullet travel horizontally?
9. A marble rolls off a tabletop 1.0 m high and hits the floor at a point 3.0 m away from the table's edge in the horizontal direction. (a) How long is the marble in the air? (b) What is the speed of the marble when it leaves the table's edge? (c) What is its speed when it hits the floor?
10. An airplane flying horizontally with a speed of 500 km/h at a height of 800 m drops a crate of supplies (see the following figure). If the parachute fails to open, how far in front of the release point does the crate hit the ground?

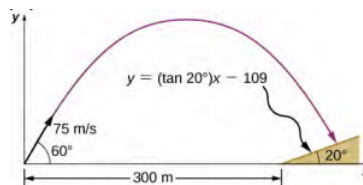


12. Suppose the airplane in the preceding problem fires a projectile horizontally in its direction of motion at a speed of 300 m/s relative to the plane. (a) How far in front of the release point does the projectile hit the ground? (b) What is its speed when it hits the ground?
13. A fastball pitcher can throw a baseball at a speed of 40 m/s (90 mi/h). (a) Assuming the pitcher can release the ball 16.7 m from home plate so the ball is moving horizontally, how long does it take the ball to reach home plate? (b) How far does the ball drop between the pitcher's hand and home plate?
14. A projectile is launched at an angle of  $30^\circ$  and lands 20 s later at the same height as it was launched. (a) What is the initial speed of the projectile? (b) What is the maximum altitude? (c) What is the range? (d) Calculate the displacement from the point of launch to the position on its trajectory at 15 s.
15. A basketball player shoots toward a basket 6.1 m away and 3.0 m above the floor. If the ball is released 1.8 m above the floor at an angle of  $60^\circ$  above the horizontal, what must the initial speed be if it were to go through the basket?
16. At a particular instant, a hot air balloon is 100 m in the air and descending at a constant speed of 2.0 m/s. At this exact instant, a girl throws a ball horizontally, relative to herself, with an initial speed of 20 m/s. When she lands, where will she find the ball? Ignore air resistance.
17. A man on a motorcycle traveling at a uniform speed of 10 m/s throws an empty can straight upward relative to himself with an initial speed of 3.0 m/s. Find the equation of the trajectory as seen by a police officer on the side of the road. Assume the initial position of the can is the point where it is thrown. Ignore air resistance.

18. An athlete can jump a distance of 8.0 m in the broad jump. What is the maximum distance the athlete can jump on the Moon, where the gravitational acceleration is onesixth that of Earth?
19. The maximum horizontal distance a boy can throw a ball is 50 m. Assume he can throw with the same initial speed at all angles. How high does he throw the ball when he throws it straight upward?
20. A rock is thrown off a cliff at an angle of  $53^\circ$  with respect to the horizontal. The cliff is 100 m high. The initial speed of the rock is 30 m/s. (a) How high above the edge of the cliff does the rock rise? (b) How far has it moved horizontally when it is at maximum altitude? (c) How long after the release does it hit the ground? (d) What is the range of the rock? (e) What are the horizontal and vertical positions of the rock relative to the edge of the cliff at  $t = 2.0$  s,  $t = 4.0$  s, and  $t = 6.0$  s?
21. Trying to escape his pursuers, a secret agent skis off a slope inclined at  $30^\circ$  below the horizontal at 60 km/h. To survive and land on the snow 100 m below, he must clear a gorge 60 m wide. Does he make it? Ignore air resistance.



22. A golfer on a fairway is 70 m away from the green, which sits below the level of the fairway by 20 m. If the golfer hits the ball at an angle of  $40^\circ$  with an initial speed of 20 m/s, how close to the green does she come?
23. A projectile is shot at a hill, the base of which is 300 m away. The projectile is shot at  $60^\circ$  above the horizontal with an initial speed of 75 m/s. The hill can be approximated by a plane sloped at  $20^\circ$  to the horizontal. Relative to the coordinate system shown in the following figure, the equation of this straight line is  $y = (\tan 20^\circ)x - 109$ . Where on the hill does the projectile land?

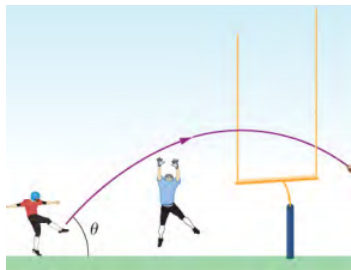


24. An astronaut on Mars kicks a soccer ball at an angle of  $45^\circ$  with an initial velocity of 15 m/s. If the acceleration of gravity on Mars is  $3.7 \text{ m/s}^2$ , (a) what is the range of the soccer kick on a flat surface? (b) What would be the range of the same kick on the Moon, where gravity is one-sixth that of Earth?
25. Mike Powell holds the record for the long jump of 8.95 m, established in 1991. If he left the ground at an angle of  $15^\circ$ , what was his initial speed?
26. MIT's robot cheetah can jump over obstacles 46 cm high and has speed of 12.0 km/h. (a) If the robot launches itself at an angle of  $60^\circ$  at this speed, what is its maximum height? (b) What would the launch angle have to be to reach a height of 46 cm?
27. Mt. Asama, Japan, is an active volcano. In 2009, an eruption threw solid volcanic rocks that landed 1 km horizontally from the crater. If the volcanic rocks were launched at an angle of  $40^\circ$  with respect to the horizontal and landed 900 m below the crater, (a) what would be their initial velocity and (b) what is their time of flight?
28. Drew Brees of the New Orleans Saints can throw a football 23.0 m/s (50 mph). If he angles the throw at  $10^\circ$  from the horizontal, what distance does it go if it is to be caught at the same elevation as it was thrown?
29. The Lunar Roving Vehicle used in NASA's late Apollo missions reached an unofficial lunar land speed of 5.0 m/s by astronaut Eugene Cernan. If the rover was moving at this speed on a flat lunar surface and hit a small bump that projected it off the surface at an angle of  $20^\circ$ , how long would it be "airborne" on the Moon?
30. A soccer goal is 2.44 m high. A player kicks the ball at a distance 10 m from the goal at an angle of  $25^\circ$ . What is the initial speed of the soccer ball?

31. Olympus Mons on Mars is the largest volcano in the solar system, at a height of 25 km and with a radius of 312 km. If you are standing on the summit, with what initial velocity would you have to fire a projectile from a cannon horizontally to clear the volcano and land on the surface of Mars? Note that Mars has an acceleration of gravity of  $3.7 \text{ m/s}^2$ .
32. In 1999, Robbie Knievel was the first to jump the Grand Canyon on a motorcycle. At a narrow part of the canyon (69.0 m wide) and traveling 35.8 m/s off the takeoff ramp, he reached the other side. What was his launch angle?
33. You throw a baseball at an initial speed of 15.0 m/s at an angle of  $30^\circ$  with respect to the horizontal. What would the ball's initial speed have to be at  $30^\circ$  on a planet that has twice the acceleration of gravity as Earth to achieve the same range? Consider launch and impact on a horizontal surface.
34. Aaron Rogers throws a football at 20.0 m/s to his wide receiver, who is running straight down the field at 9.4 m/s. If Aaron throws the football when the wide receiver is 10.0 m in front of him, what angle does Aaron have to launch the ball at so the receiver catches it 20.0 m in front of Aaron?
35. A crossbow is aimed horizontally at a target 40 m away. The arrow hits 30 cm below the spot at which it was aimed. What is the initial velocity of the arrow?
36. A long jumper can jump a distance of 8.0 m when he takes off at an angle of  $45^\circ$  with respect to the horizontal. Assuming he can jump with the same initial speed at all angles, how much distance does he lose by taking off at  $30^\circ$ ?
37. On planet Arcon, the maximum horizontal range of a projectile launched at 10 m/s is 20 m. What is the acceleration of gravity on this planet?
38. A mountain biker encounters a jump on a race course that sends him into the air at  $60^\circ$  to the horizontal. If he lands at a horizontal distance of 45.0 m and 20 m below his launch point, what is his initial speed?

### Challenge Problems

99. World's Longest Par 3. The tee of the world's longest par 3 sits atop South Africa's Hanglip Mountain at 400.0 m above the green and can only be reached by helicopter. The horizontal distance to the green is 359.0 m. Neglect air resistance and answer the following questions. (a) If a golfer launches a shot that is  $40^\circ$  with respect to the horizontal, what initial velocity must she give the ball? (b) What is the time to reach the green?
100. When a field goal kicker kicks a football as hard as he can at  $45^\circ$  to the horizontal, the ball just clears the 3-m-high crossbar of the goalposts 45.7 m away. (a) What is the maximum speed the kicker can impart to the football? (b) In addition to clearing the crossbar, the football must be high enough in the air early during its flight to clear the reach of the onrushing defensive lineman. If the lineman is 4.6 m away and has a vertical reach of 2.5 m, can he block the 45.7-m field goal attempt? (c) What if the lineman is 1.0 m away?



101. A truck is traveling east at 80 km/h. At an intersection 32 km ahead, a car is traveling north at 50 km/h. (a) How long after this moment will the vehicles be closest to each other? (b) How far apart will they be at that point?

### Contributors and Attributions

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