ANSWER KEY. Values match the simulation readouts for the settings given in each step.

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Projectile Motion Virtual Lab

Physics | ANSWER KEY

Open **activities.zornscience.org/projectile-lab/** and follow each step. The simulation uses g = 9.80 m/s^2 and no air resistance. Show your work with units.

Objective

Use a launched ball and its velocity vectors to find how the **horizontal** and **vertical** parts of a projectile's motion change during a flight, and what sets its **time in the air** and **range**.

NGSS alignment: HS-PS2-1. Analyze data to support the claim that Newton's second law describes the relationship among the net force on an object, its mass, and its acceleration (here, a constant downward acceleration from gravity).
Practices and concepts: Analyzing and interpreting data; Using mathematics and computational thinking; Patterns; Cause and effect.

Meet the simulation

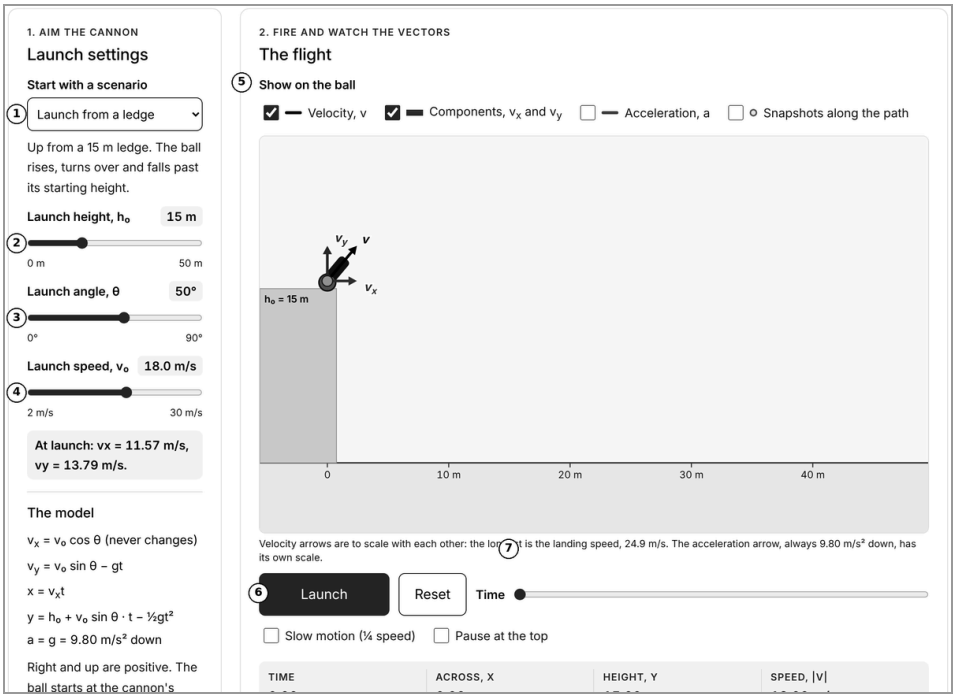


Figure 1. The Projectile Motion Vector Lab.

(1) Scenario menu: loads a ready-made launch.

(2) Launch height, h_0.

(3) Launch angle, θ, above horizontal.

(4) Launch speed, v_0.

(5) Check boxes for the velocity, component, acceleration and snapshot arrows.

(6) Fires the ball.

(7) Time slider: moves to any time. Click it, then use the arrow keys to step 0.05 s, or press End to jump to the landing.

Readouts and Flight results are below the scene.

Pre-lab

1. A ball is launched at 20 m/s, 45° above horizontal. Calculate its horizontal (v_x) and vertical (v_y) velocity components at launch.

$v_x = v_0 \cos\theta$ = (20 m/s)(cos 45°) = 14.14 m/s; $v_y = v_0 \sin\theta$ = (20 m/s)(sin 45°) = 14.14 m/s

2. Predict: at the very top of its path, what is the ball's velocity? What is its acceleration?

Velocity is not zero: $v_y = 0$, but v_x is still 14.14 m/s to the right. Acceleration is still 9.80 m/s^2 down.

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Part A. Watch the components change

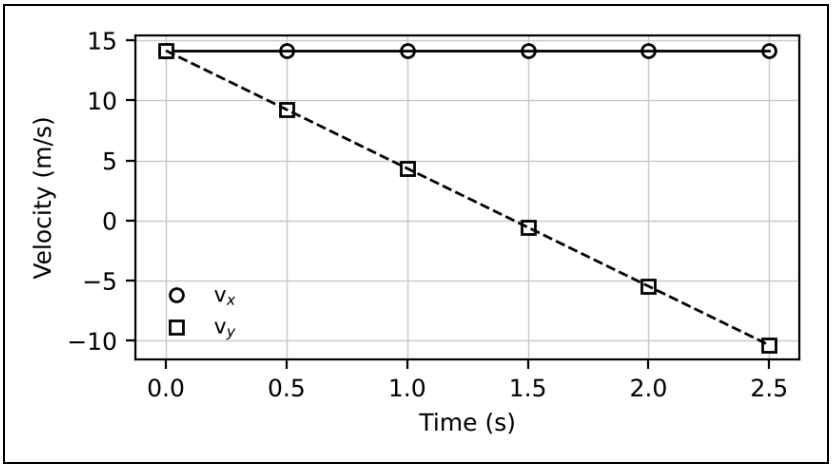
1. Choose the scenario **Ground to ground at 45°** (h_0 = 0 m, θ = 45°, v_0 = 20.0 m/s). Check **Acceleration, a** and select **Launch** to watch.
2. Move the Time slider to each time in the table and record the readouts. Write a velocity that says "down" as a **negative** number.

TIME	ACROSS, X	HEIGHT, Y	SPEED, |v|
1.50 s	21.21 m	10.19 m	14.15 m/s
v_x	v_y	ACCELERATION	DIRECTION
14.14 m/s right	0.56 m/s down	9.80 m/s² down	2° below horizontal

Figure 2. The readouts at 1.50 s.

Time (s)	x (m)	y (m)	v_x (m/s)	v_y (m/s)	Change in v_y since last row (m/s)
0.00	**0.00**	**0.00**	**14.14**	**14.14**	none
0.50	**7.07**	**5.85**	**14.14**	**9.24**	**−4.90**
1.00	**14.14**	**9.24**	**14.14**	**4.34**	**−4.90**
1.50	**21.21**	**10.19**	**14.14**	**−0.56**	**−4.90**
2.00	**28.28**	**8.68**	**14.14**	**−5.46**	**−4.90**
2.50	**35.36**	**4.73**	**14.14**	**−10.36**	**−4.90**

3. Graph v_x and v_y against time on the same grid. Use a different symbol for each, and draw a best-fit line for each. Label both axes with units.



v_x: flat line at 14.14 m/s.
v_y: straight line sloping down, crossing zero near 1.44 s.

4. Find the slope of each line with units. What does each slope tell you about the acceleration in that direction?

v_x: slope = (14.14 m/s − 14.14 m/s) / (2.50 s − 0 s) = <u>0 m/s²</u>, no horizontal acceleration.
v_y: slope = (−10.36 m/s − 14.14 m/s) / (2.50 s − 0 s) = <u>−9.80 m/s²</u>, a constant 9.80 m/s² downward acceleration (g).

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5. Press **End** on the Time slider. Record the Flight results: time in the air, highest point, range, and v_y at landing. How does v_y at landing compare with v_y at launch?

Time 2.89 s; highest point 10.20 m at 1.44 s; range 40.82 m; v_y at landing = −14.14 m/s. Same size as at launch (14.14 m/s), opposite direction.

6. Look at the x column. The ball moves the same distance across every 0.50 s. Explain why, using the arrows you saw on the ball.

Each 0.50 s it moves 7.07 m across. The v_x arrow never changes length, and the acceleration arrow points straight down, so nothing speeds up or slows down the horizontal motion.

Part B. Horizontal launch from a cliff

1. Set h_0 = 40 m and θ = 0°. For each launch speed in the table, press End on the Time slider and record the Flight results.
2. For trial 4, change the height to h_0 = 10 m with v_0 = 12 m/s.

Trial	h_0 (m)	v_0 (m/s)	Time in the air (s)	Range (m)	v_y at landing (m/s)
1	40	6	**2.86**	**17.14**	**−28.00**
2	40	12	**2.86**	**34.29**	**−28.00**
3	40	18	**2.86**	**51.43**	**−28.00**
4	10	12	**1.43**	**17.14**	**−14.00**

7. Does launch speed change the time in the air for a horizontal launch? What does it change? Use trials 1 to 3.

No. The time is 2.86 s for all three speeds, because the vertical motion starts at $v_y = 0$ every time. Speed changes only the range: doubling v_0 from 6 to 12 m/s doubles the range from 17.14 to 34.29 m.

8. Use $\Delta y = \frac{1}{2}gt^2$ to calculate the time to fall 40 m. Then calculate the range for trial 2 with $x = v_x t$. Compare with the simulation.

$t = \sqrt{(2\Delta y / g)} = \sqrt{(2(40\text{ m}) / 9.80\text{ m/s}^2)} =$ <u>2.86 s</u>
$x = (12\text{ m/s})(2.86\text{ s}) =$ <u>34.3 m</u>. Both match the simulation (2.86 s and 34.29 m).

9. Compare trials 2 and 4. The height is 4 times larger in trial 2. How many times longer is the time in the air? Explain using $\Delta y = \frac{1}{2}gt^2$.

2.86 s / 1.43 s = 2 times longer. Since $\Delta y = \frac{1}{2}gt^2$, the time depends on the square root of the height: $\sqrt{4} = 2$.

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Part C. Launch angle and range

1. Set h_0 = 0 m and v_0 = 20 m/s. For each angle, press End on the Time slider and record the Flight results.

Angle θ (°)	15	30	45	60	75
Time in the air (s)	1.06	2.04	2.89	3.53	3.94
Highest point (m)	1.37	5.10	10.20	15.31	19.04
Range (m)	20.41	35.35	40.82	35.35	20.41

10. Which angle gives the longest range? Which pairs of angles give the same range? Why does a steep launch stay in the air longer but not go farther?

45° (40.82 m). 15° and 75° tie (20.41 m), and 30° and 60° tie (35.35 m). A steep launch has a large v_y (more time in the air) but a small v_x, so it covers less distance each second.

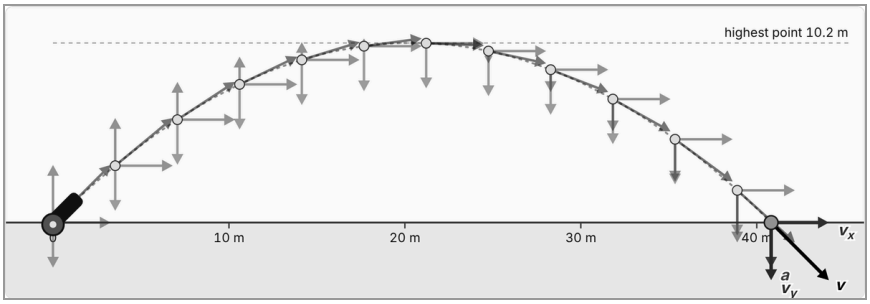


Figure 3. Snapshots every 0.25 s for the 45° launch at 20 m/s.

Set θ = 45°. Check **Snapshots along the path** and **Acceleration, a**, then press End on the Time slider.

11. In Figure 3, describe what the horizontal arrows, the vertical velocity arrows and the acceleration arrows each do from launch to landing.

Horizontal (v_x) arrows stay the same length. Vertical (v_y) arrows point up and shrink, are zero at the top, then point down and grow. Acceleration arrows point straight down and never change.

12. A real ball moves through air. Would the real range at 45° and 20 m/s be longer, shorter or the same as 40.82 m? Explain.

Shorter. Air resistance pushes opposite the motion, so v_x decreases during the flight instead of staying 14.14 m/s, and the ball covers less distance.

Conclusion

13. Write a claim that answers the objective. Support it with specific numbers from Parts A and B, then explain your reasoning using the direction of the acceleration.

Claim: The horizontal velocity stays constant, while the vertical velocity changes by 9.80 m/s each second. Time in the air depends on the vertical motion; range depends on v_x and that time.
Evidence: In Part A, v_x stayed 14.14 m/s while v_y fell by 4.90 m/s every 0.50 s. In Part B, every 40 m launch took 2.86 s, and the range grew with speed (17.14, 34.29, 51.43 m).
Reasoning: Gravity is the only force, and it points straight down. So the acceleration is 9.80 m/s^2 down and zero sideways.

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