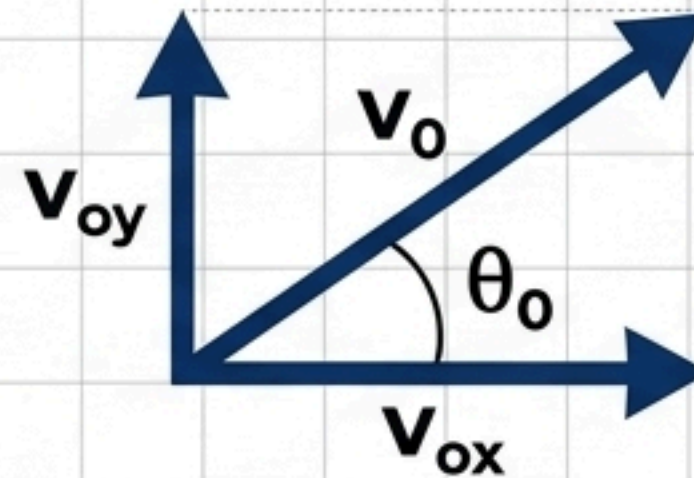


Motion in a Plane · Concept 8.

Projectile Motion

Deconstructing two-dimensional flight into independent one-dimensional motions.





KINEMATIC BLUEPRINT: PROJECTILE MOTION

VELOCITY VECTOR RESOLUTION & INDEPENDENT MOTION

HORIZONTAL: CONSTANT VELOCITY

X-AXIS BLUEPRINT

$$a_x = 0$$

$$v_{0x} = v_0 \cos \theta_0$$

Moves forward smoothly.
Acceleration is zero.

VERTICAL: FREE-FALL

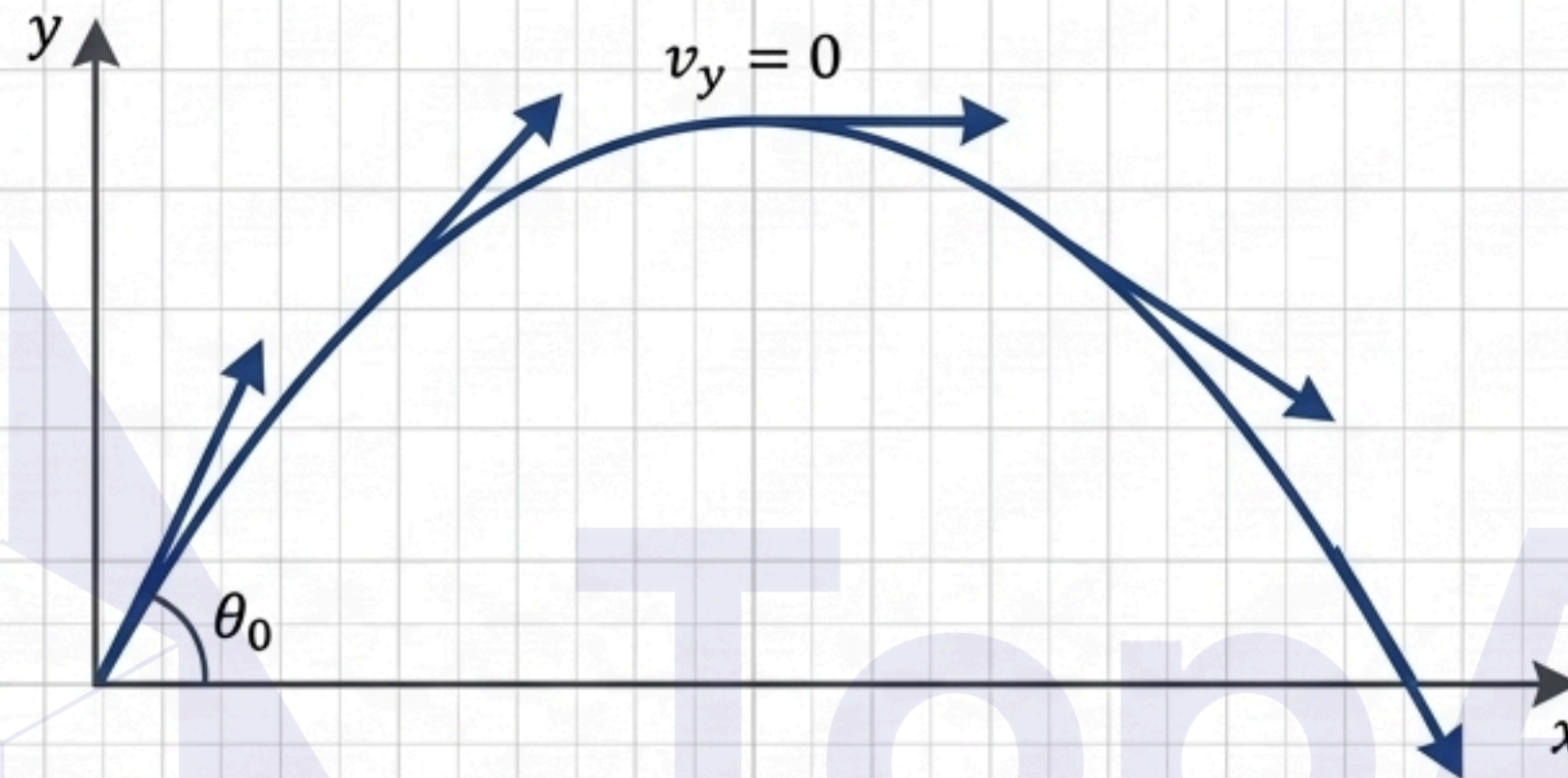
Y-AXIS BLUEPRINT

$$a_y = -g \hat{j}$$

$$v_{0y} = v_0 \sin \theta_0$$

Accelerates downward due to gravity,
exactly like a dropped object.

DERIVING THE PARABOLIC EQUATION OF PATH



Transformation Timeline

Step 1

x-position:

$$x = (v_0 \cos \theta_0)t$$

Step 2

y-position:

$$y = (v_0 \sin \theta_0)t - \frac{1}{2}gt^2$$

Step 3

The Synthesis

Eliminate time t

Hero equation bloction

Equation of Path (Parabola)

$$y = (\tan \theta_0)x - \left[\frac{g}{2(v_0 \cos \theta_0)^2} \right] x^2$$



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$$E=mc^2$$



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Time to Max Height & Total Flight

$$t_m = \frac{v_0 \sin \theta_0}{g}$$

$$T_f = 2t_m = \frac{2v_0 \sin \theta_0}{g}$$



Maximum Height (h_m)

Occurs when $v_y = 0$

$$h_m = \frac{(v_0 \sin \theta_0)^2}{2g}$$

Horizontal Range (R)

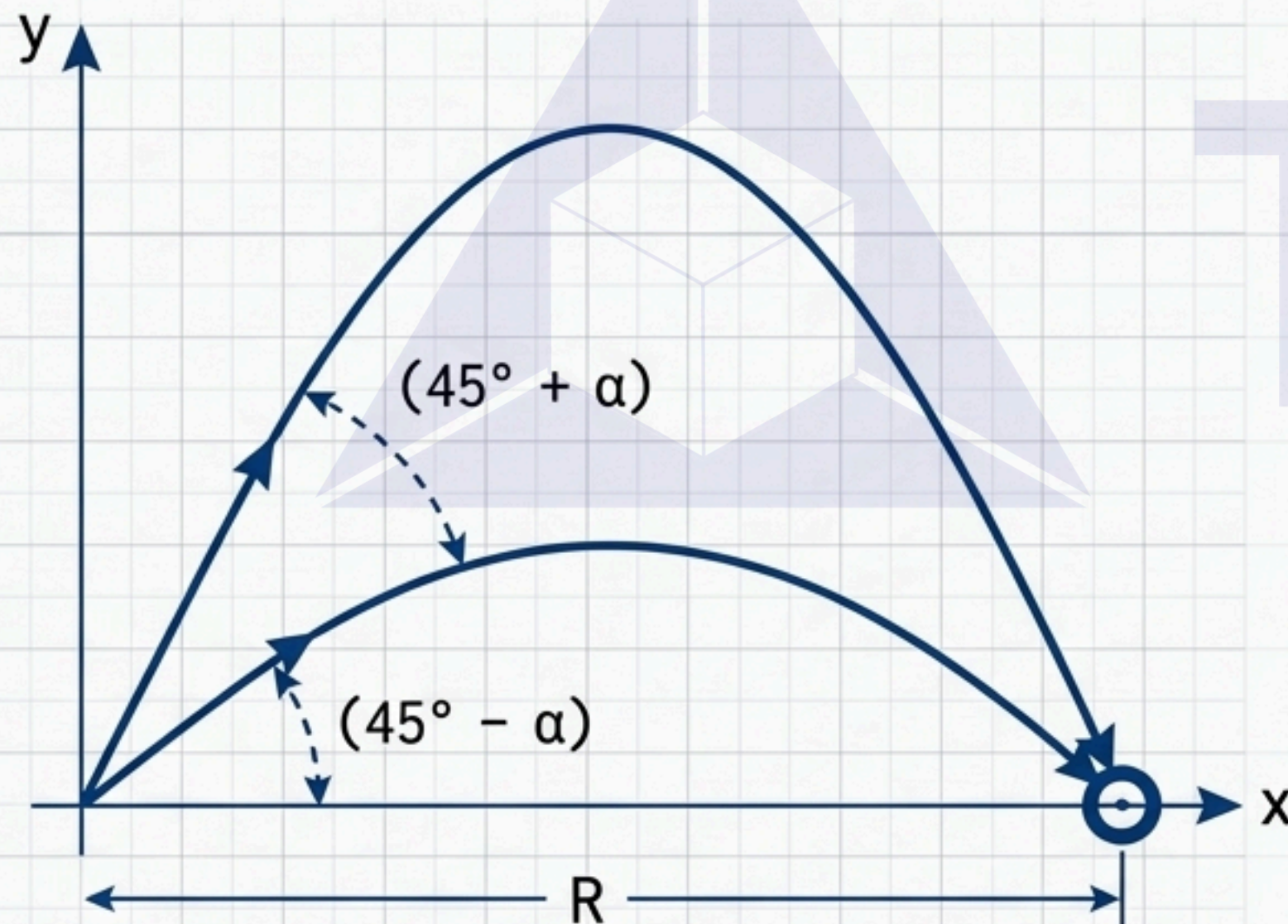
$$R = \frac{v_0^2 \sin 2\theta_0}{g}$$

Maximum Range:

$R_m = \frac{v_0^2}{g}$ occurs
precisely at $\theta_0 = 45^\circ$

Galileo's Equal-Range Symmetries

*"For elevations which **exceed** or **fall short** of 45° by equal amounts, the ranges are equal."* — Galileo Galilei



Range relies on $\sin(2\theta_0)$.

$$\sin(2(45^\circ + \alpha)) = \sin(90^\circ + 2\alpha) = \cos(2\alpha)$$

$$\sin(2(45^\circ - \alpha)) = \sin(90^\circ - 2\alpha) = \cos(2\alpha)$$

Conclusion: Identical sine values yield identical ranges.



TRAP ALERT

Complementary angles around 45° give EQUAL ranges, not just the angle exactly at 45° — and horizontal velocity (v_x) never changes during flight.

Example 3.7: A hiker stands on the edge of a cliff 490 m above the ground and throws a stone horizontally with an initial speed of 15 m/s. Neglecting air resistance, find the time taken to reach the ground and the landing speed. ($g = 9.8 \text{ m/s}^2$)

Time of flight: $y = \frac{1}{2}gt^2 \Rightarrow 490 = \frac{1}{2}(9.8)t^2 \Rightarrow t = 10 \text{ s}$

Landing speed: $v_x = 15 \text{ m/s}$ (constant)
 $v_y = gt = 9.8 \times 10 = 98 \text{ m/s}$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{15^2 + 98^2} \approx 99 \text{ m/s}$$



Example 3.8: A cricket ball is thrown at a speed of 28 m/s in a direction 30° above the horizontal. Calculate (a) the maximum height, (b) the time of flight, and (c) the horizontal range.

Given: $v_0 = 28 \text{ m/s}$, $\theta_0 = 30^\circ$, $g = 9.8 \text{ m/s}^2$

Height: $h_m = (28 \sin 30^\circ)^2 / 2(9.8) = 10.0 \text{ m}$

Time: $T_f = 2(28 \sin 30^\circ) / 9.8 = 2.9 \text{ s}$

Range: $R = (28^2 2 \sin 60^\circ) / 9.8 = 69 \text{ m}$

✓ Key Takeaways

Horizontal component constant, vertical component free-fall-like; range is maximum only at exactly 45° , equal for symmetric angles around it.

- Path is a geometric parabola:

$$y = x \tan \theta_0 - \frac{gx^2}{2(v_0 \cos \theta_0)^2}$$

- X and Y dimensions function with absolute independence.



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