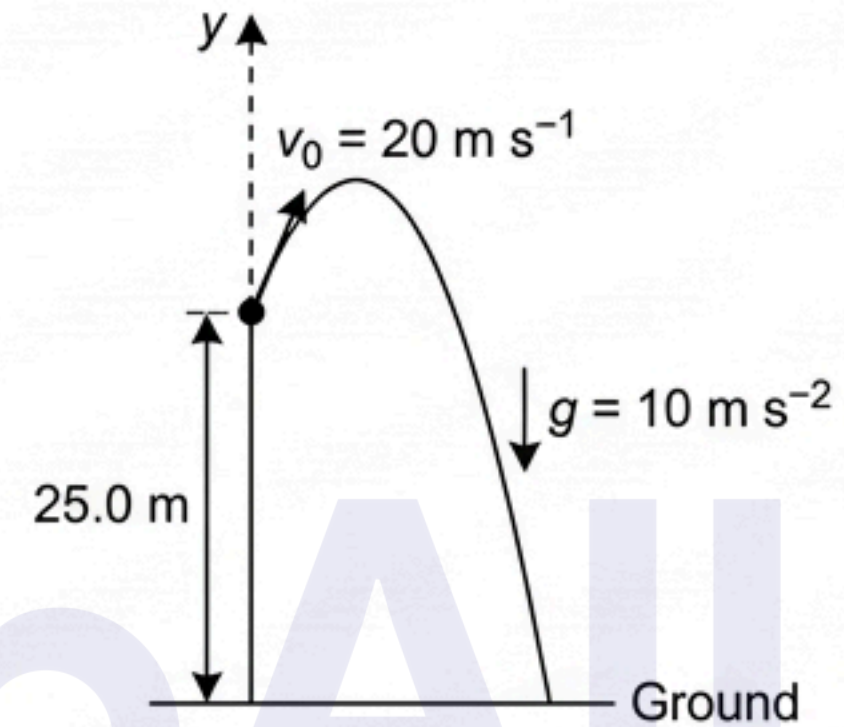


Motion in a Straight Line · Concept 4

Applications of Kinematic Equations — Free Fall, Galileo's Odd-Number Law, Stopping Distance & Reaction Time

EXAMPLE 2.3

A ball is thrown vertically upwards with a velocity of 20 m s^{-1} from the top of a multistorey building. The height of the point from where the ball is thrown is 25.0 m from the ground. Take $g = 10 \text{ m s}^{-2}$. What is the total time taken by the ball before it hits the ground?



A) 3 s

B) 4 s

C) 5 s

D) 6 s

Solving the Challenge — Two Methods

Method 1: Split Path

- **Step 1:** Upward motion to peak ($v = 0$). Calculates $t_1 = 2$ s.
- **Step 2:** Free-fall from the peak at 45 m to the ground. Calculates $t_2 = 3$ s.
- **Result:**
Total time $= 2 + 3 = 5$ s.

Method 2: Vector Displacement (The Pro Way)

A single kinematic equation respects the entire path natively.

$$y - y_0 = v_0 t + 0.5 a t^2$$

$$\begin{array}{ll} y = 0 & y_0 = 25 \\ v_0 = 20 & a = -10 \end{array}$$

$$\begin{aligned} 0 &= 25 + 20t - 5t^2 \\ 5t^2 - 20t - 25 &= 0 \\ t &= 5 \text{ s} \end{aligned}$$

APPLICATION 1

Pure Free Fall

Free fall occurs when an object is released near the Earth's surface and accelerated downward by gravity alone (neglecting air resistance, $a = -g = -9.8 \text{ m s}^{-2}$).

When initial velocity ($v_0 = 0$) and initial position ($y_0 = 0$) are zeroed out, the standard equations transform into their purest forms:

$$v = -9.8t \text{ (m s}^{-1}\text{)}$$

$$y = -4.9t^2 \text{ (m)}$$

$$v^2 = -19.6y \text{ (m}^2 \text{ s}^{-2}\text{)}$$



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$$E=mc^2$$



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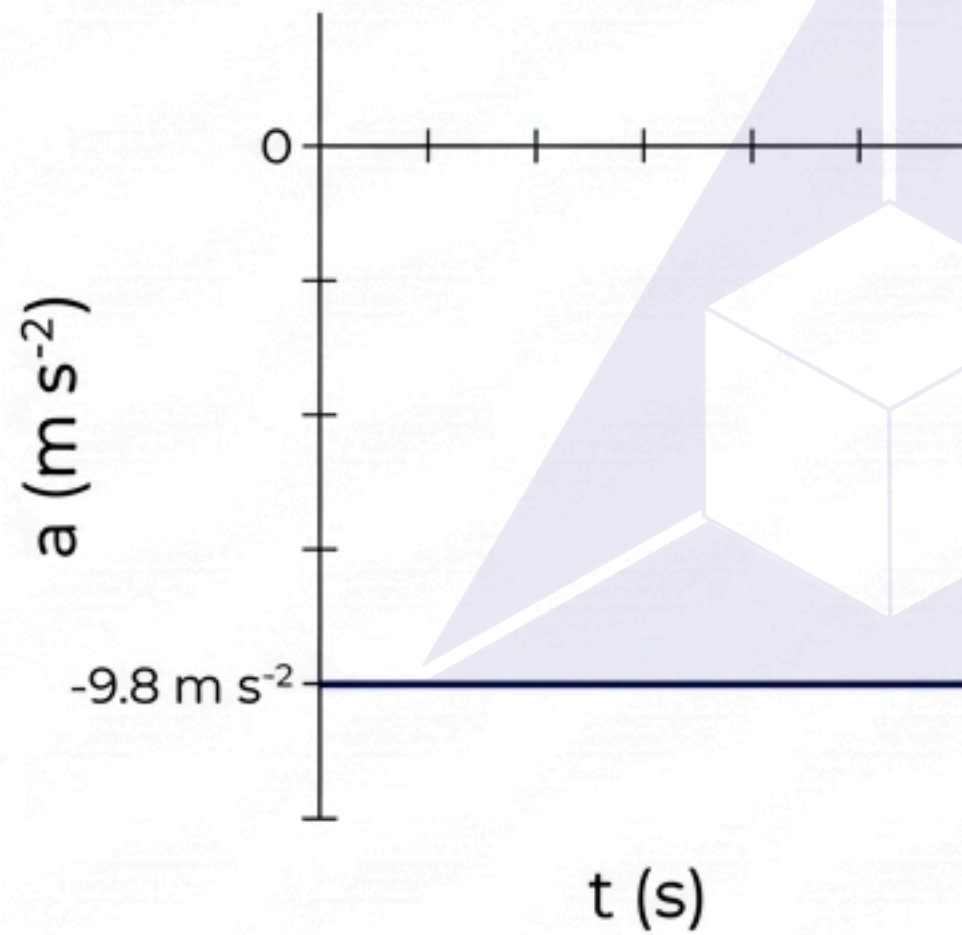
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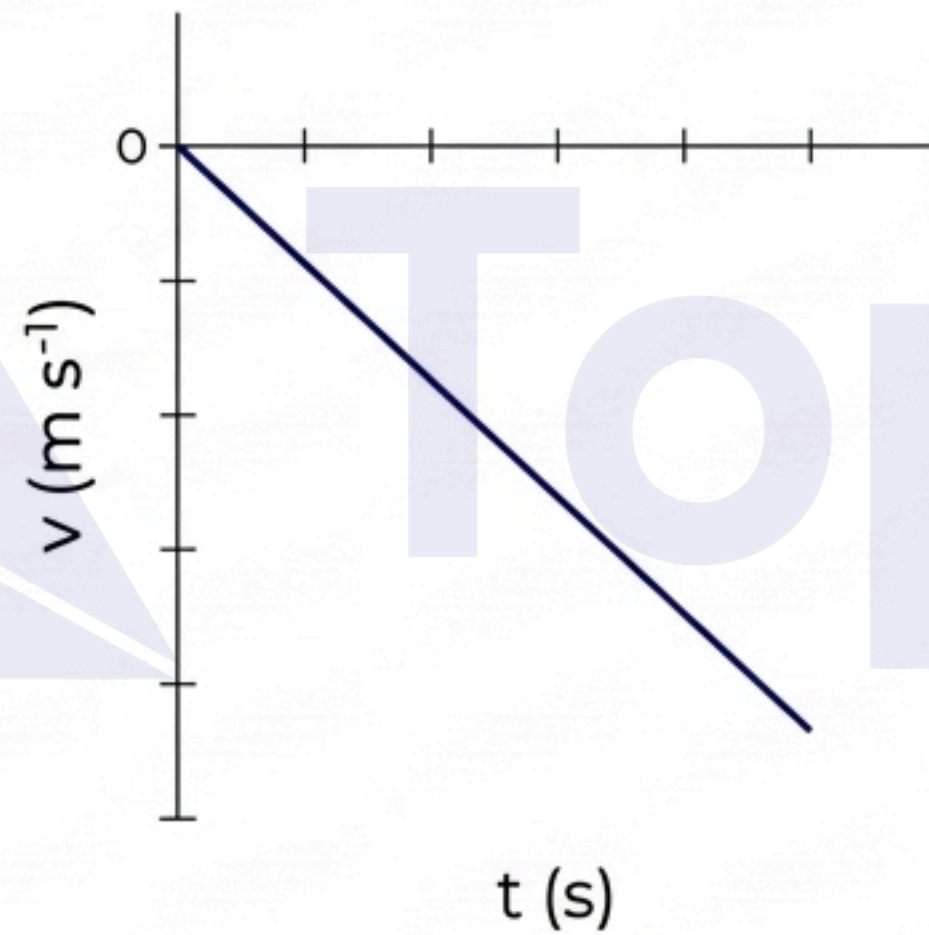
Free Fall in Graphs

Acceleration



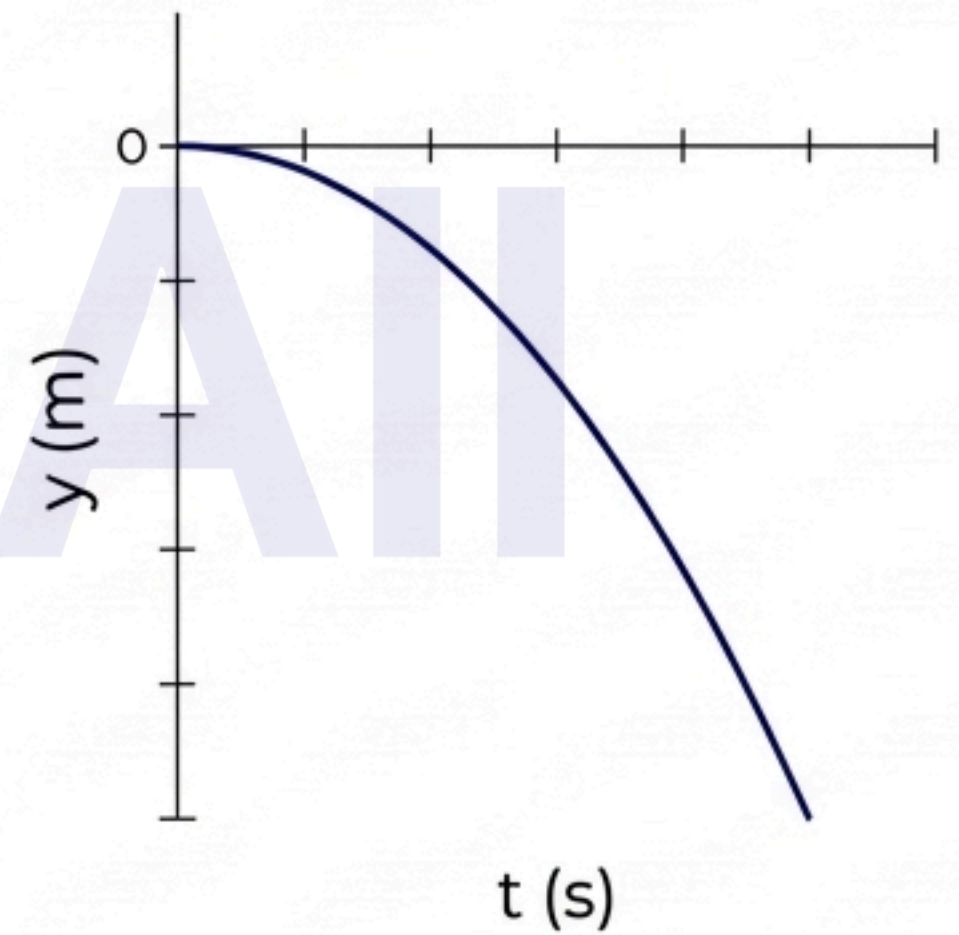
$$a = -9.8 \text{ m s}^{-2}$$

Velocity



$$v = -9.8t$$

Position



$$y = -4.9t^2$$

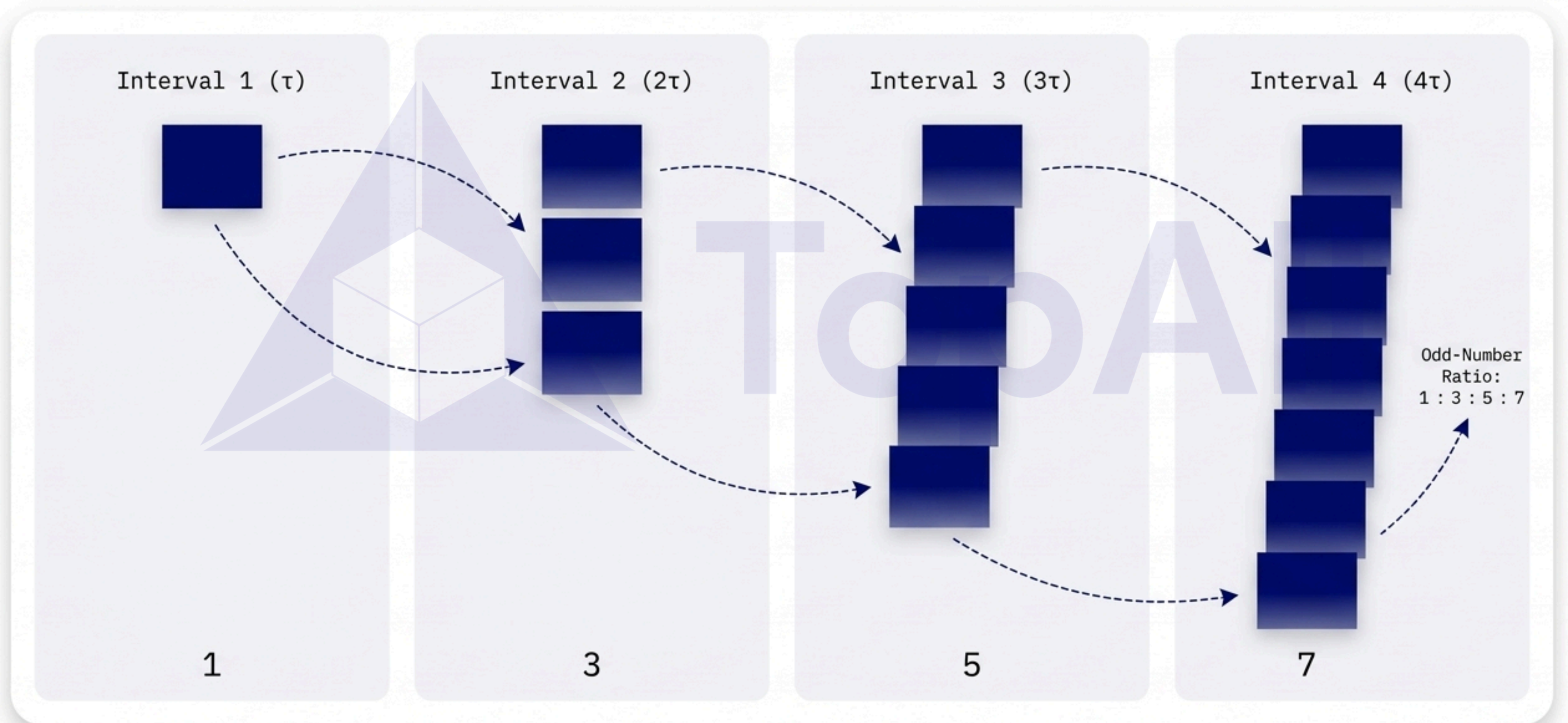
APPLICATION 2

Galileo's Odd-Number Law

“ The distances traversed, during equal intervals of time, by a body falling from rest, stand to one another in the same ratio as the odd numbers beginning with unity. ”

Time Intervals	Position Coords ($y = -0.5g\tau^2$)	Distance Traversed in Interval	Final Ratio
0	0	0	—
τ	y_0	y_0	1
2τ	$4y_0$	$3y_0$	3
3τ	$9y_0$	$5y_0$	5
			7...

Galileo's Law Visualized



APPLICATION 3

Stopping Distance

Theoretical Derivation

Calculating the distance (d_s) a vehicle travels before stopping when brakes are applied (deceleration $-a$).

- Start with: $v^2 = v_0^2 + 2ax$
- Set final velocity $v = 0$ (vehicle stops)
- $0 = v_0^2 - 2ad_s$

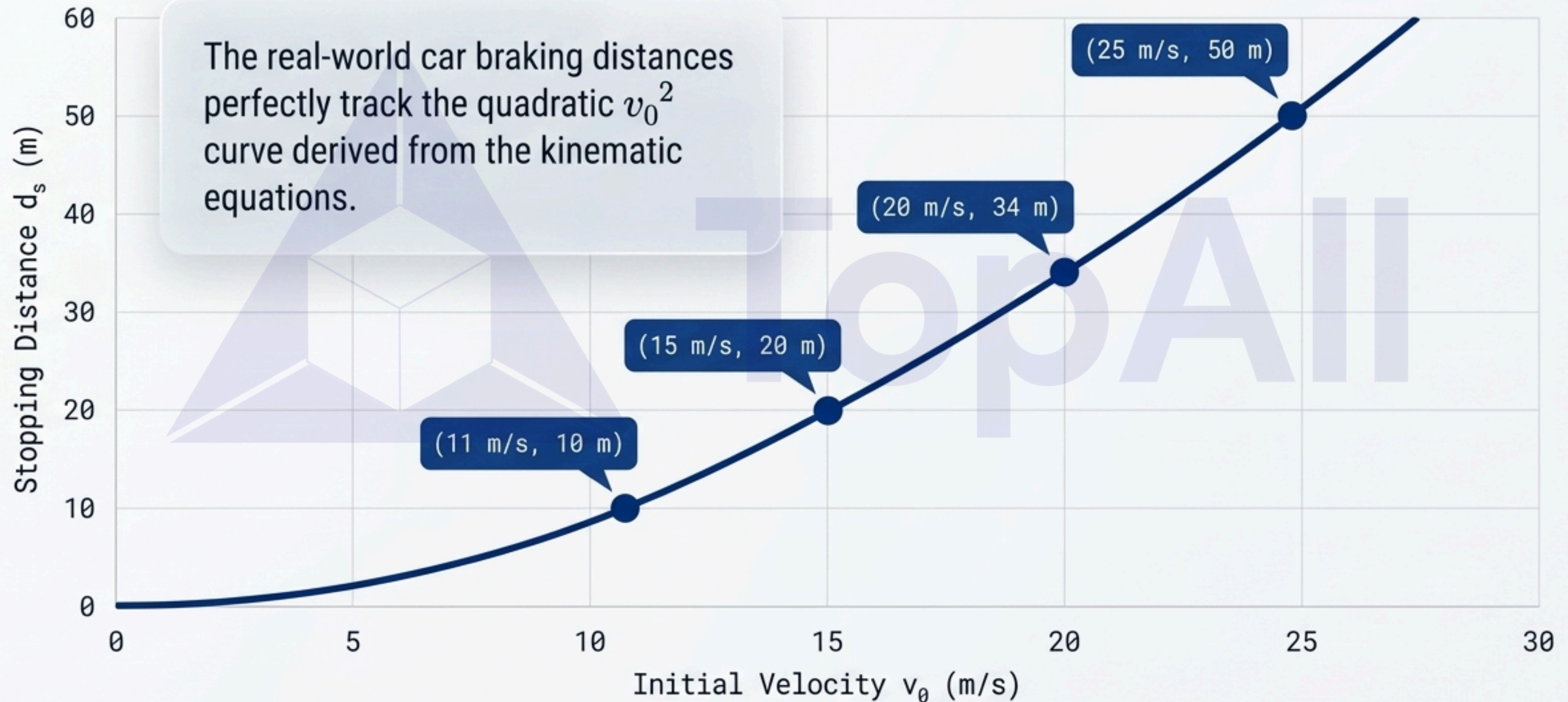
Hero Equation

$$d_s = \frac{-v_0^2}{2a}$$

Insight:

Stopping distance is directly proportional to the square of the initial velocity (v_0^2).

Stopping Distance in the Real World

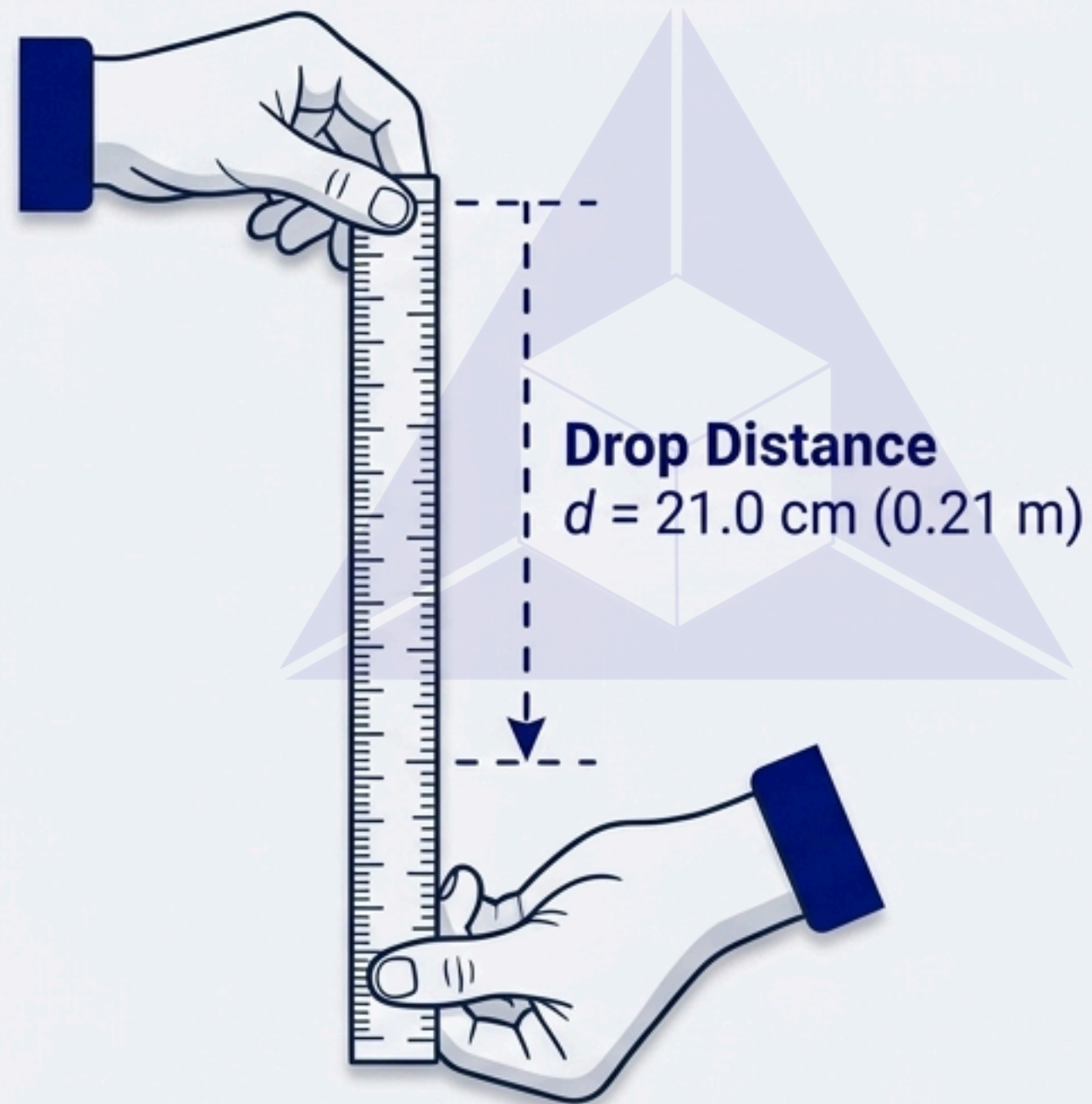


! TRAP ALERT

The Velocity Squared Trap

Stopping distance scales with v_0^2 . Doubling your initial speed does NOT double your stopping distance — it **quadruples it (increases by a factor of 4)**.

Measuring Reaction Time



The ruler drops under free fall. Initial velocity $v_0 = 0$, acceleration $a = -9.8 \text{ m s}^{-2}$. In an experiment, the ruler drops distance $d = 21.0 \text{ cm (0.21 m)}$.

$$d = \frac{1}{2}gt_r^2$$

$$t_r = \sqrt{\frac{2d}{g}}$$

$$t_r = \sqrt{\frac{2 \times 0.21}{9.8}} \approx 0.2 \text{ s}$$

Insight: The kinematic math transforms a simple distance measurement on a ruler into a precise measurement of biological reaction time.

✓ SUMMARY

Key Takeaways

One set of kinematic equations, four entirely distinct physical scenarios:

1. The vertical trajectories of pure free fall.
2. The geometric 1:3:5 symmetry of Galileo's odd-number ratio.
3. The horizontal, v_0^2 -scaled reality of vehicular stopping distances.
4. The measurement of human reaction time via a dropping ruler.



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