Constant Acceleration and Free Fall



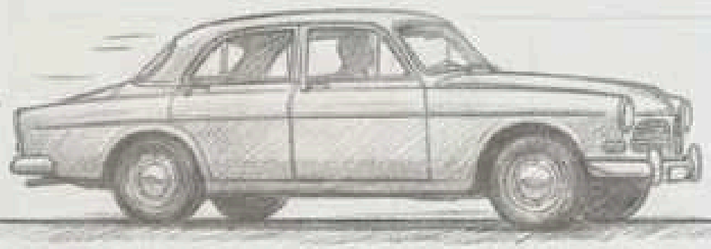
At a glance — The three equations of constant acceleration, stopping distances, and free fall near the Earth.

From Description to Prediction

Describing Motion

Predicting Motion

When acceleration is constant, a few short equations unlock the future — telling us exactly where an object will be and how fast it will move.





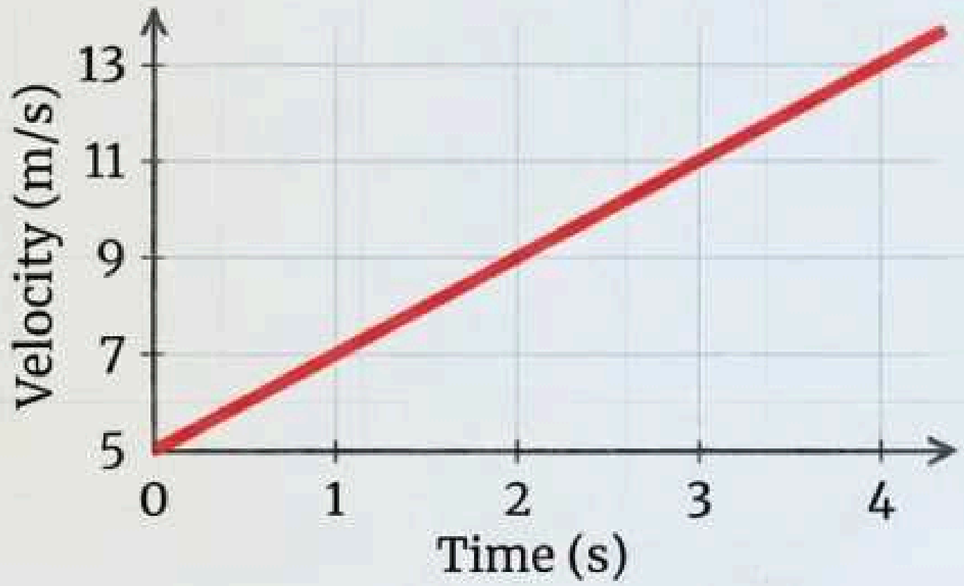
Equation 1: Velocity Over Time

$$v_f = v_0 + at$$

Starting speed

Rate of change: +2 m/s every second

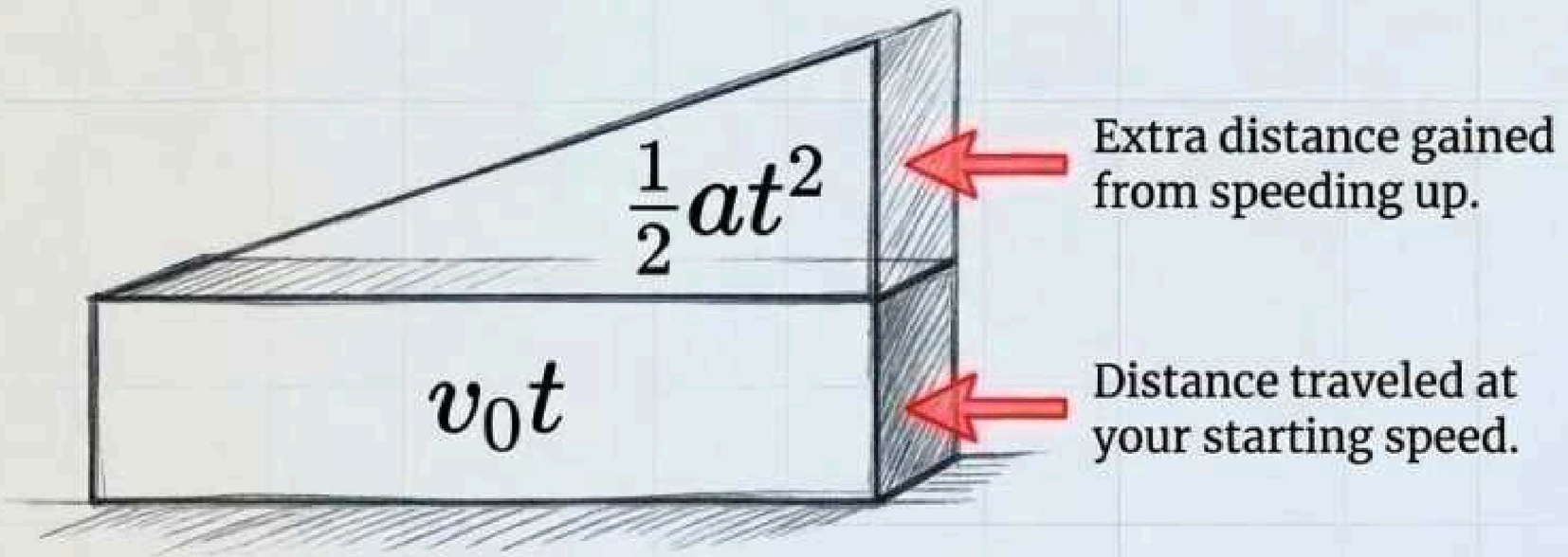
Duration



Acceleration is simply the rate of change of velocity.

Equation 2: Position Over Time

$$d = v_0 t + \frac{1}{2} a t^2$$

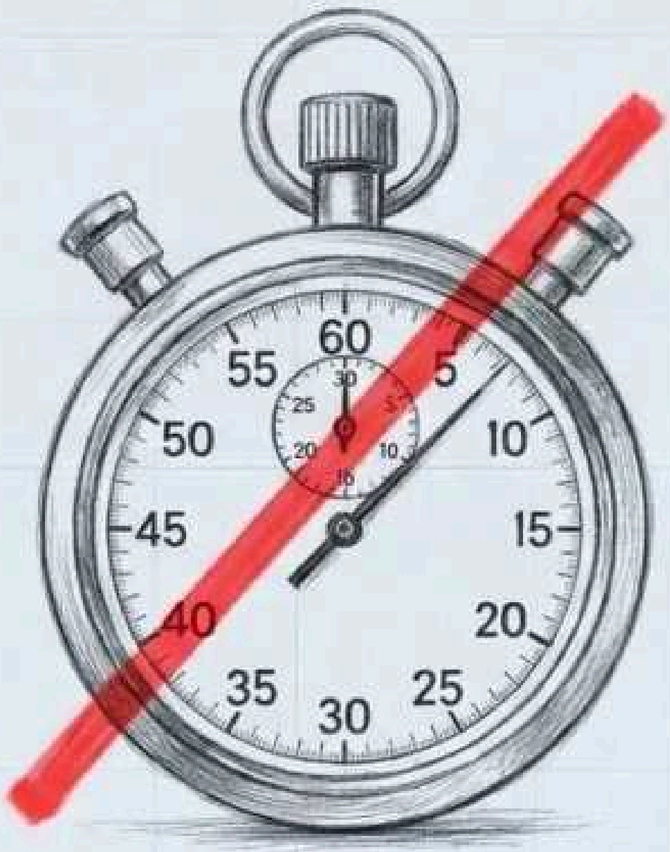


Growth accelerates with the square of time.

Equation 3: The Timeless Link

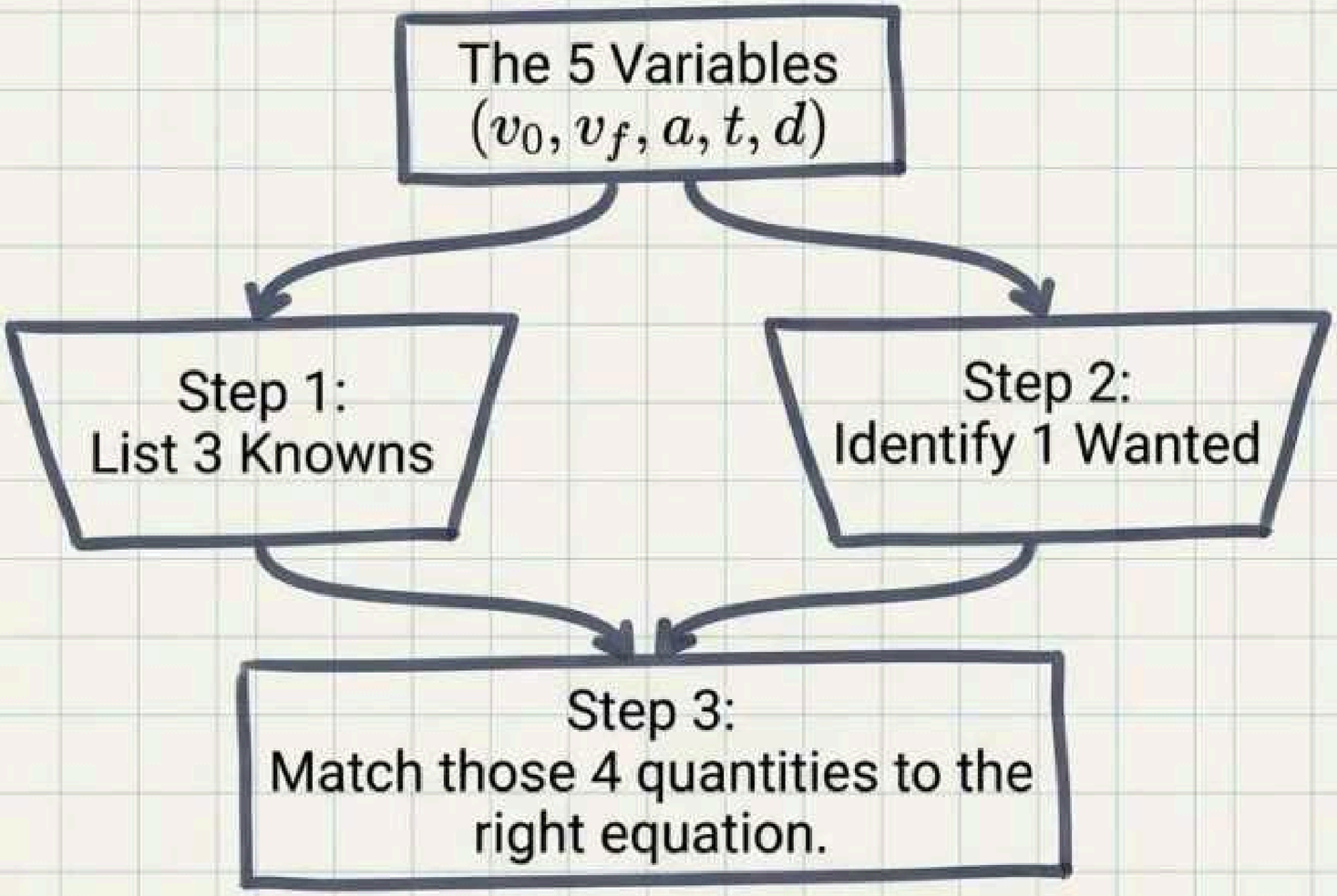
$$v_f^2 = v_0^2 + 2ad$$

Links velocity and distance without mentioning time.



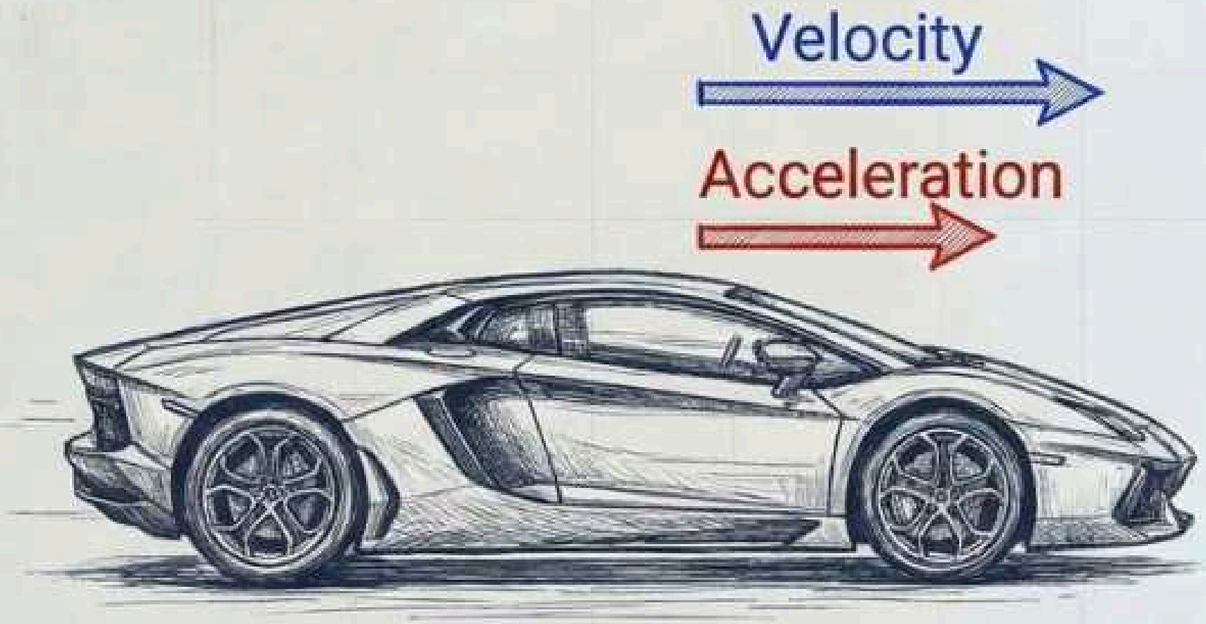
THE FINE PRINT: These three equations apply only when acceleration is constant.

The Equation Selection Algorithm



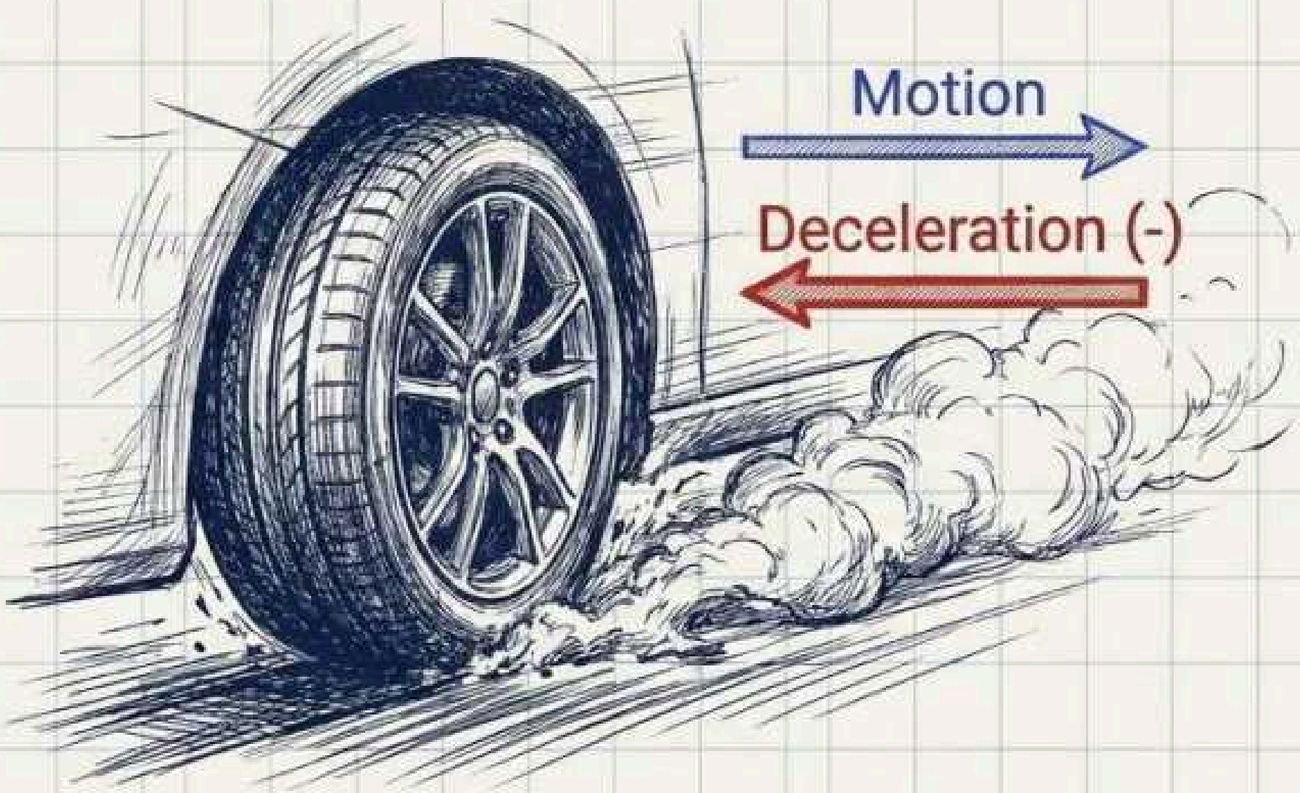
This habit turns a confusing story problem into a simple search.

Example 1: Acceleration



Diagnostic Matrix
Known: $v_0 = 0, a = 2.5 \frac{\text{m}}{\text{s}^2}, v_f = 20 \frac{\text{m}}{\text{s}}$
Want: Time (t), Distance (d)
Solution 1 (Time): $t = \frac{20}{2.5} = 8$ seconds
Solution 2 (Distance): $d = \frac{1}{2} * 2.5 * 8^2 = 80$ meters

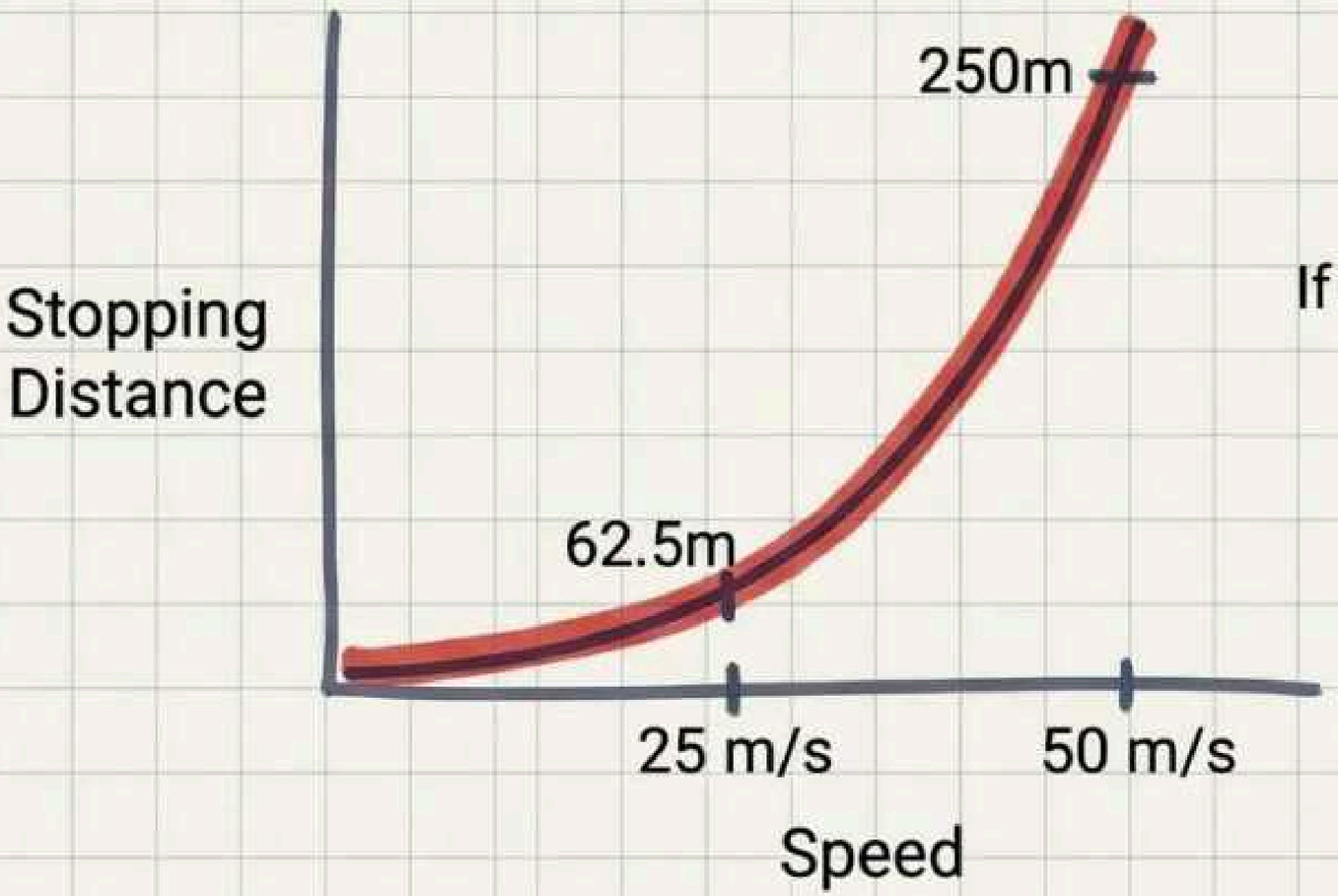
Example 2: Braking



Diagnostic Matrix
Known: $v_0 = 25\,\frac{\text{m}}{\text{s}}, v_f = 0, a = -5\,\frac{\text{m}}{\text{s}^2}$
Want: Stopping Distance (d)
Solution: Use Equation 3 (no time). $$d = \frac{25^2}{2 * 5} = \frac{625}{10} = 62.5 \text{ meters}$$

Stopping time is 5 seconds.

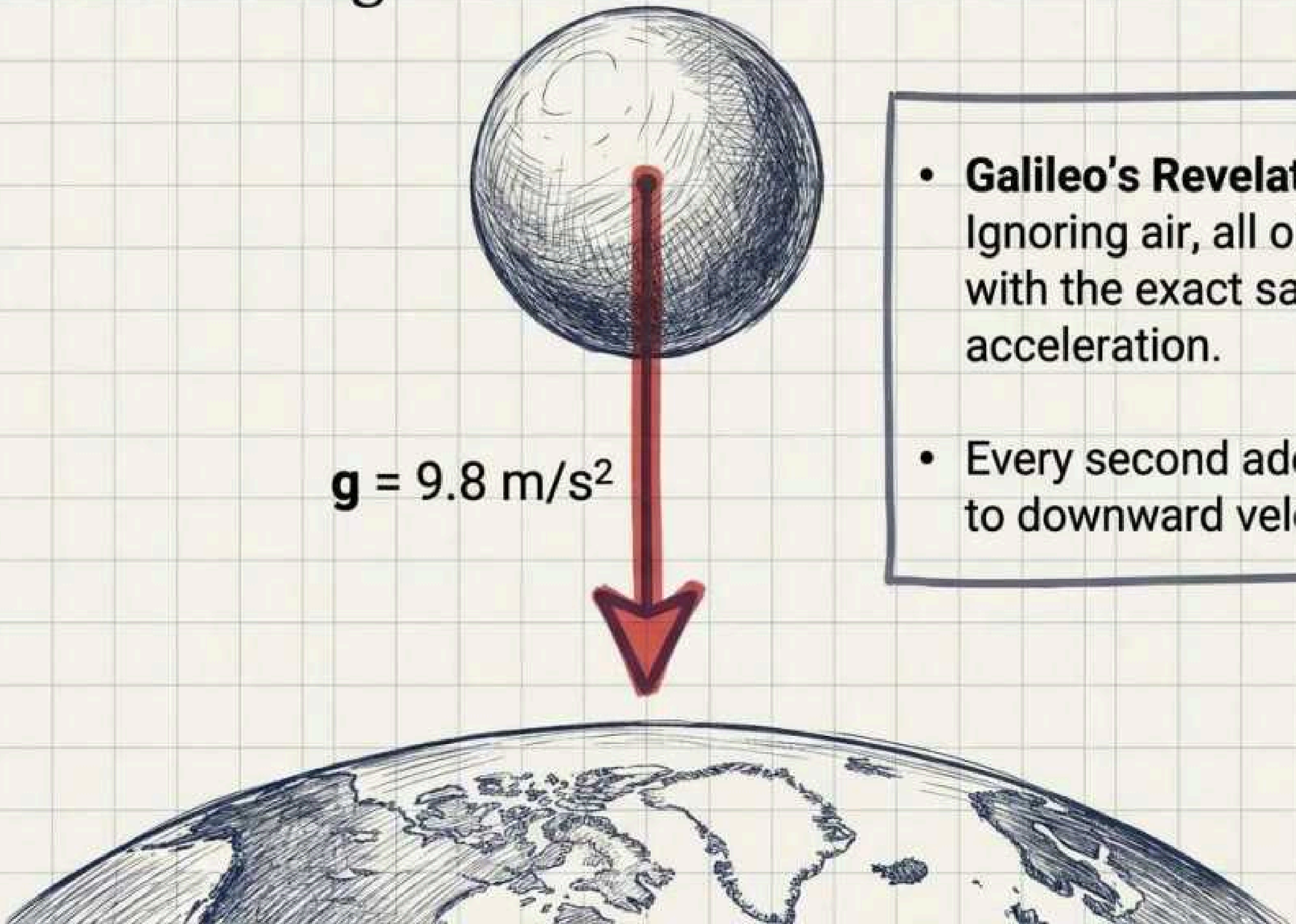
The Danger of the Square



If starting speed doubles, stopping distance QUADRUPLES. Speed is squared.

This is why speed limits and larger gaps matter at highway speeds.

Free Fall and “Little g”



- **Galileo’s Revelation:** Ignoring air, all objects fall with the exact same acceleration.
- Every second adds $9.8\ \frac{\text{m}}{\text{s}^2}$ to downward velocity.

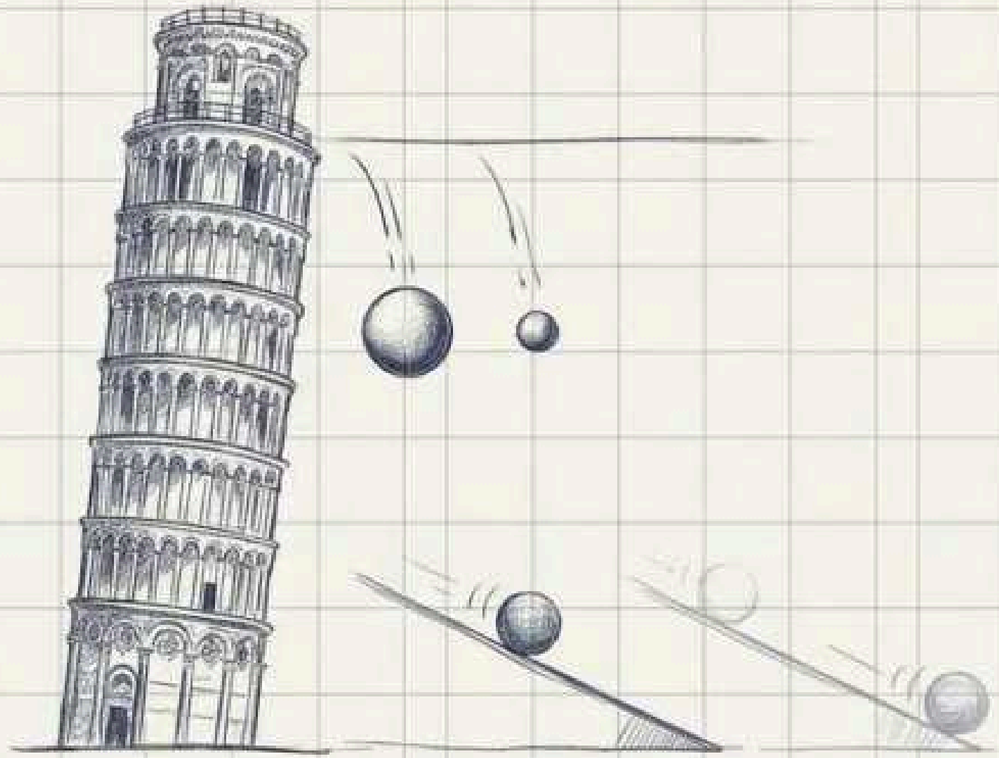
A Radical Idea: Aristotle vs. Galileo

Aristotle's View



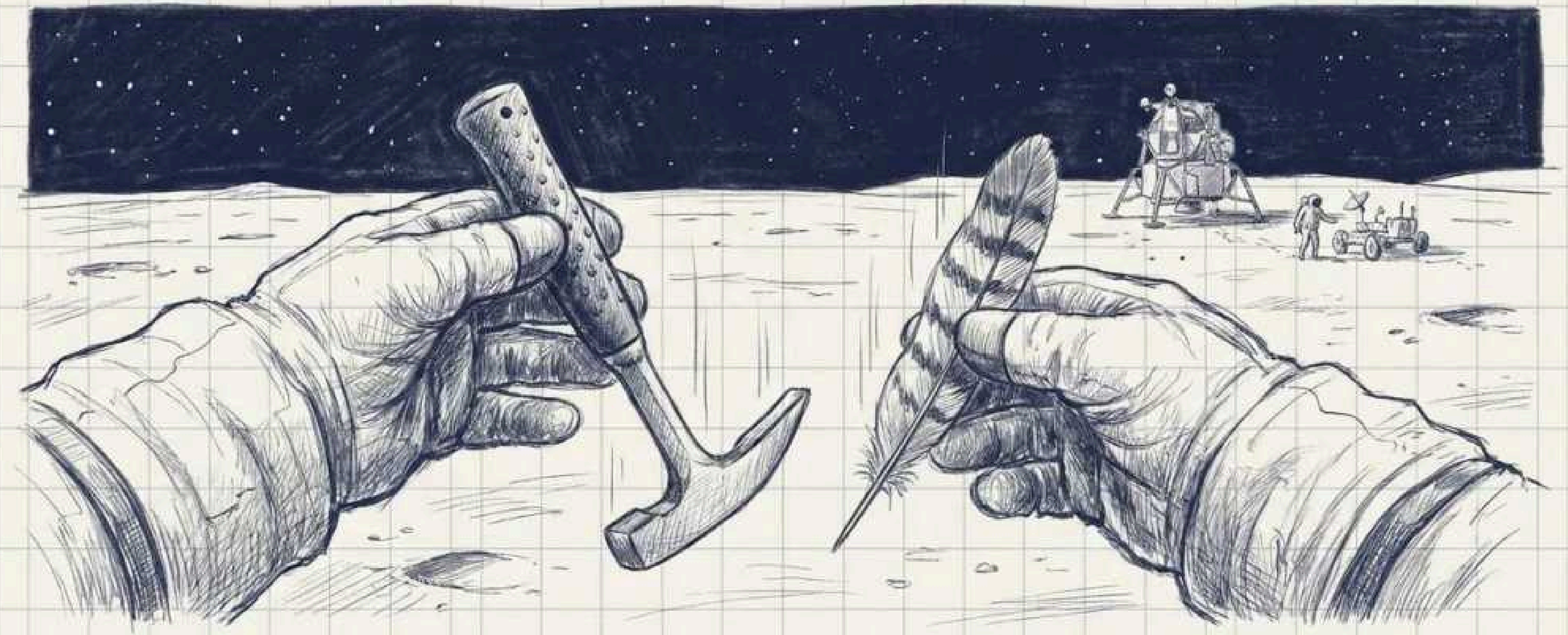
Intuition: Heavy objects fall faster.

Galileo's View



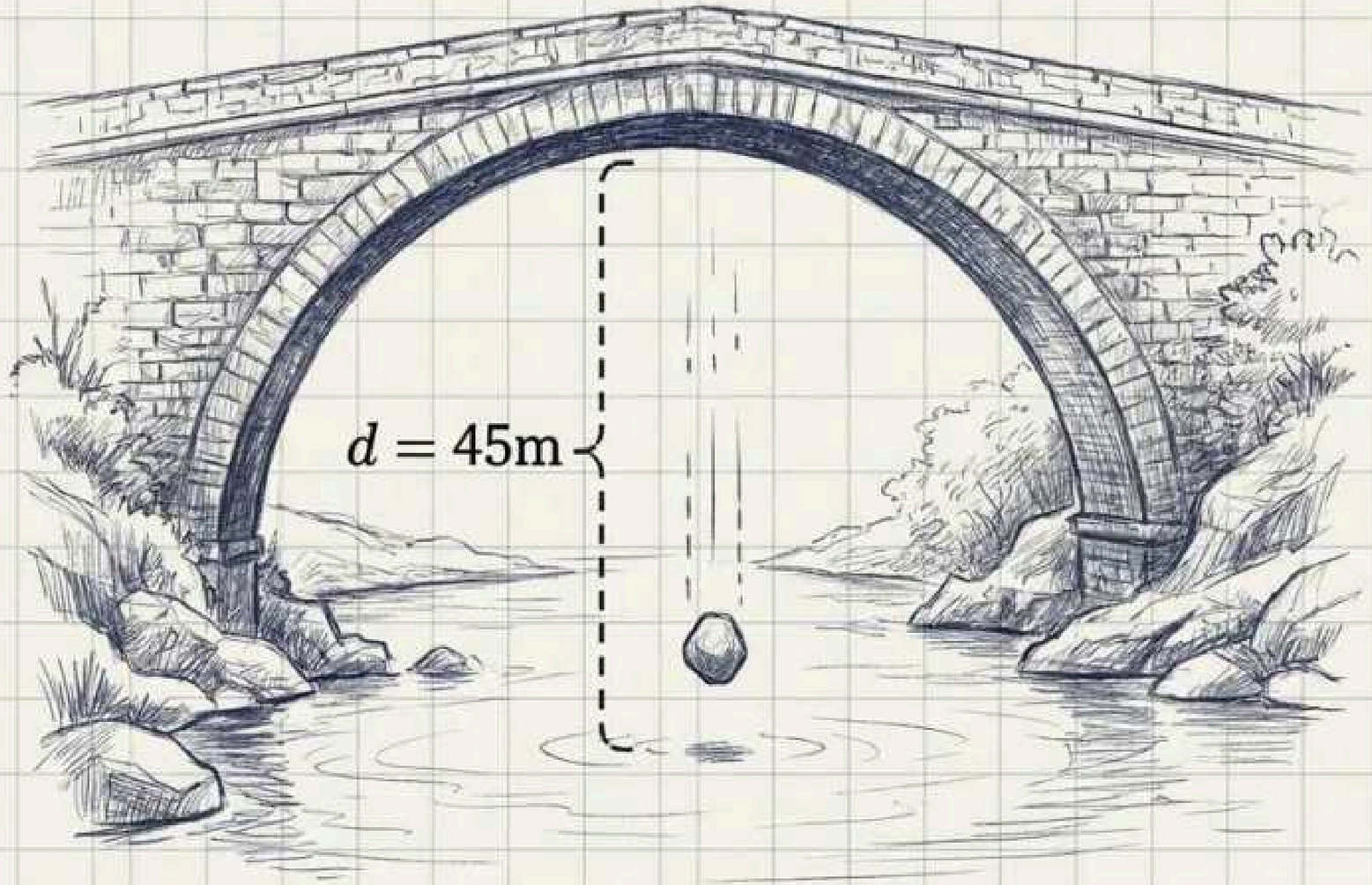
Experiment: Gravity gives all objects the same acceleration.

The Ultimate Demonstration (1971)



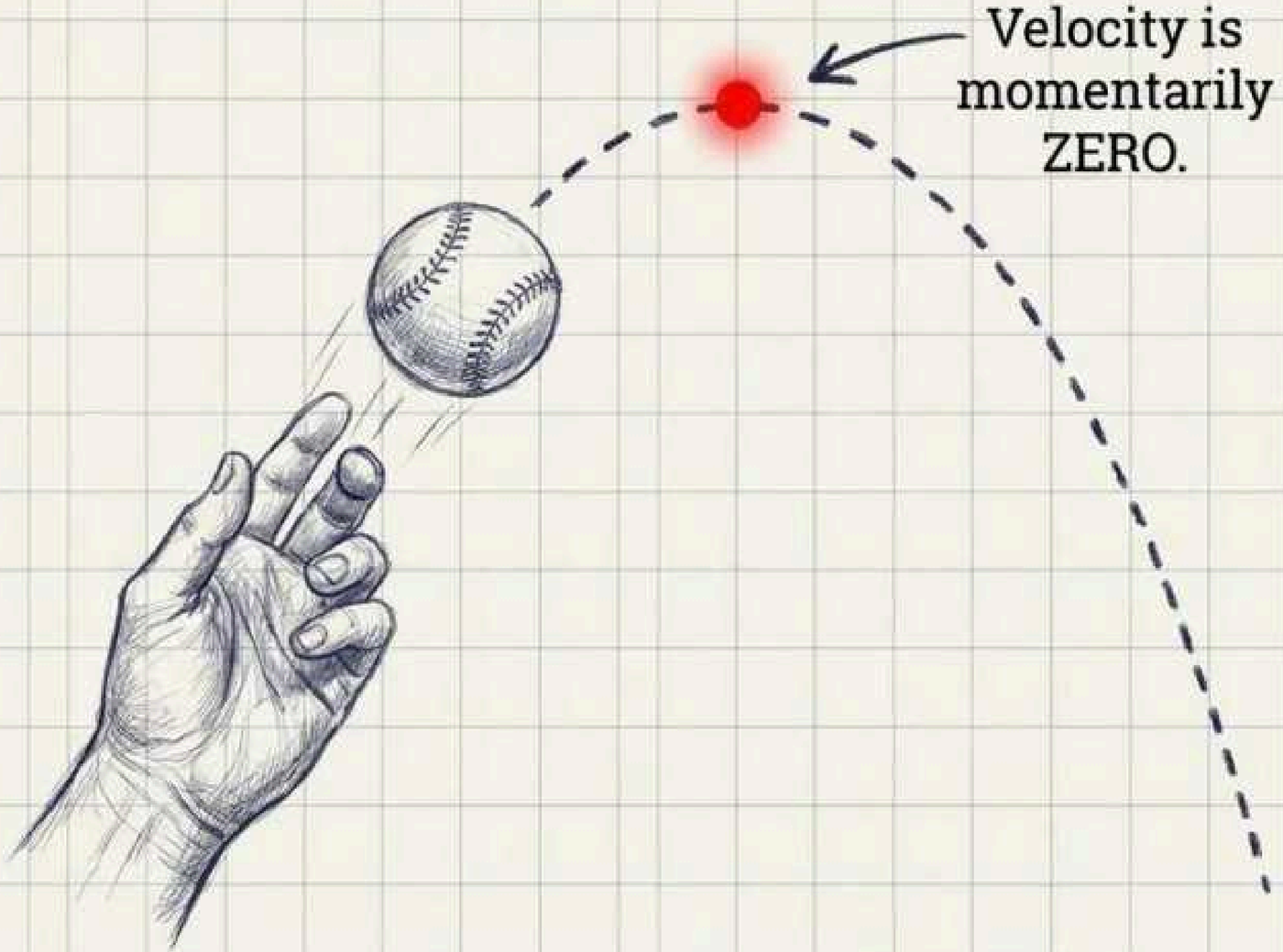
David Scott on the Moon. Zero air resistance. Both hit the ground at the exact same moment. On Earth, air resistance makes a feather drift, but the physics of gravity itself is universal.

Example 3: Dropping a Stone



Diagnostic Matrix
Known: $d = 45\text{m}$, $v_0 = 0$, $a = 9.8\ \text{m/s}^2$ Want: Time (t), Final Speed (v_f)
Solution (Time): $t = 3.03$ seconds Solution (Impact Speed): $9.8 * 3.03 = 29.7\ \text{m/s}$

Example 4: The Vertical Throw



Known (Upward Phase):

$$v_0 = 20 \text{ m/s}$$

Time to top:

$20 / 9.8 = 2.04$ seconds

Height reached:

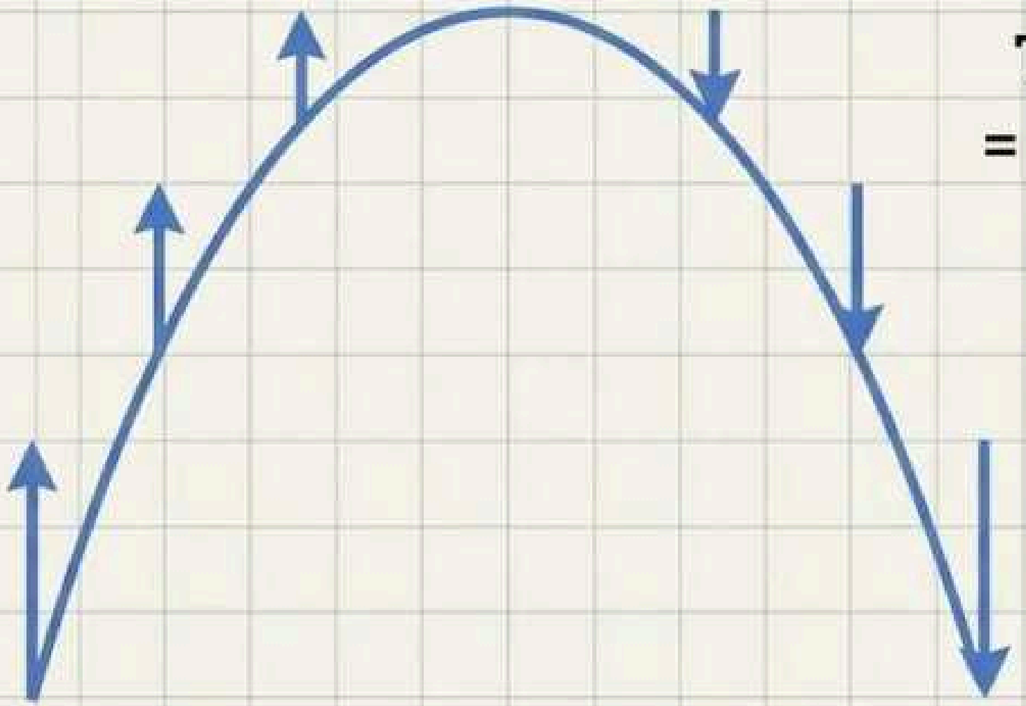
$$\frac{20^2}{2 * 9.8} = 20.4 \text{ meters}$$

Total round trip:

4.08 seconds

The Symmetry of Gravity

Gravity is fair.



Time rising (2.04s)
= Time falling (2.04s).

It passes each height going up at the exact same speed it passes coming down.

Returns to the hand at 20 m/s, just pointing the other way.

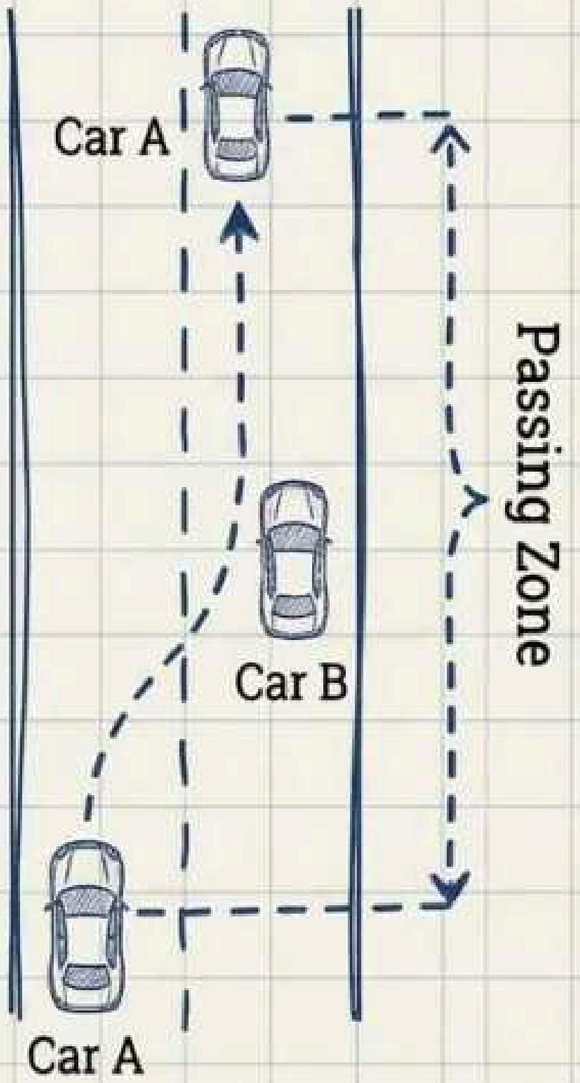
Three Cautions for Real Physics

1. Direction: Choose a positive direction and stick to it (If Up is positive, then g = -9.8).

2. Never Zero: Acceleration is NEVER zero during a throw. Gravity acts all the time, even at the very top.

3. The Model vs. Reality: Air resistance matters for light or fast objects. Our equations are an excellent model, but not the whole truth.

Example 5: Overtaking



Overtake Planner
Known: v_0 = 15 m/s, a = 1 m/s^2, t = 10 s
Final Speed: 15 + 10 = 25 m/s
Distance Needed: Cruising distance (15 · 10) = 150m Acceleration distance (0.5 · 1 · 100) = 50m Total passing distance = 200 meters

The Hidden Part of Stopping



Braking at 25 m/s:

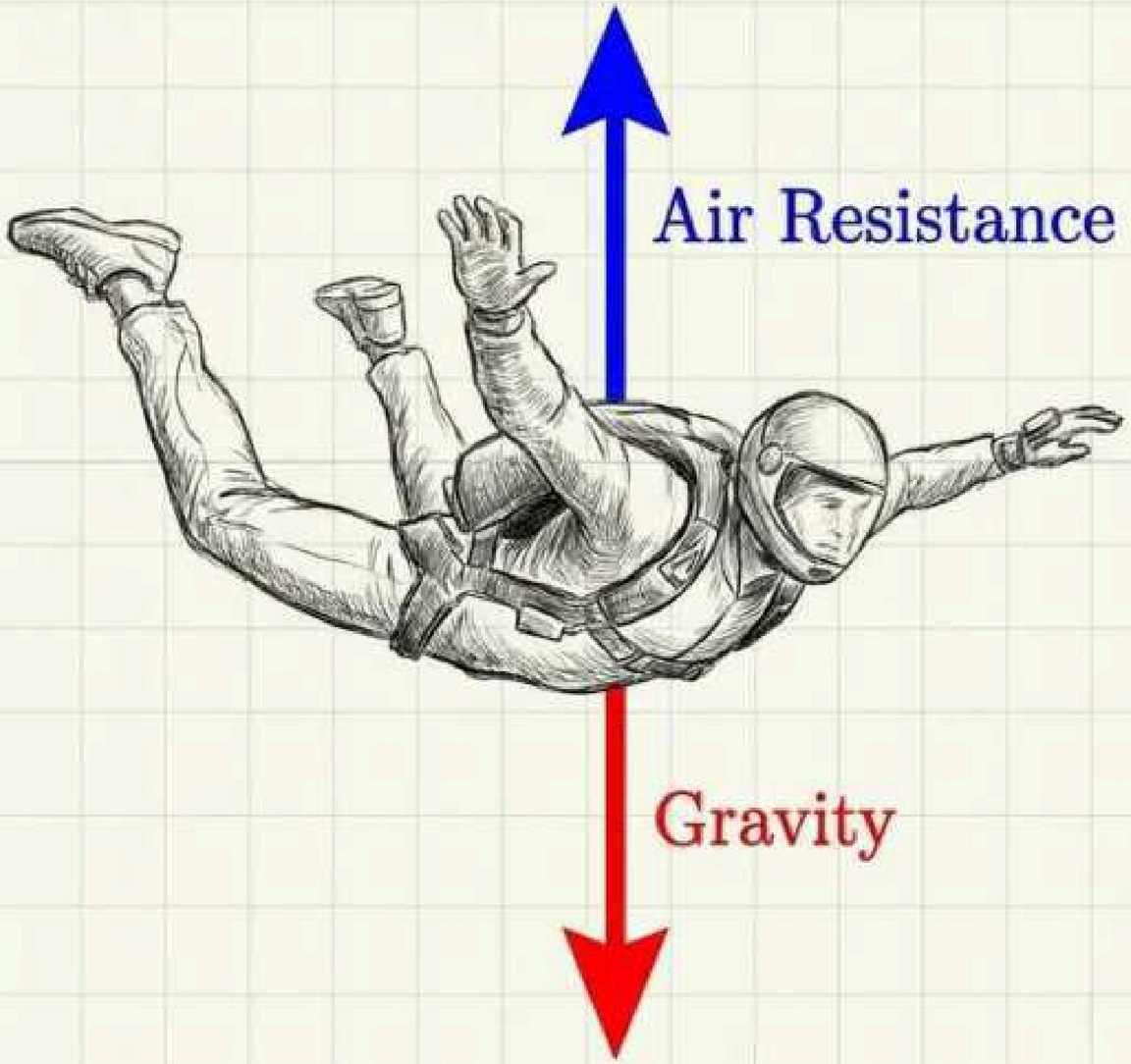
Hazard noticed → Brake pressed: 37.5 meters traveled completely blindly.

Actual Braking: 62.5 meters.

Total Stopping Distance: 100 meters.

A distracted driver needs even more.

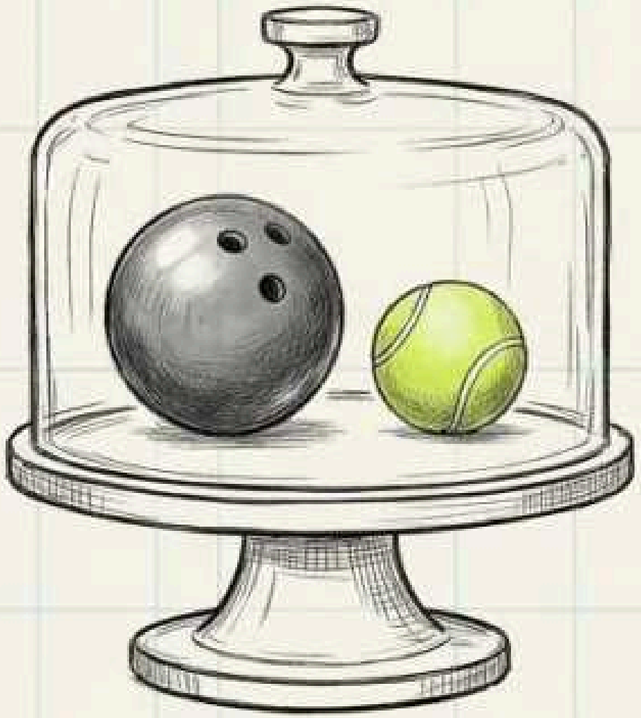
Terminal Velocity



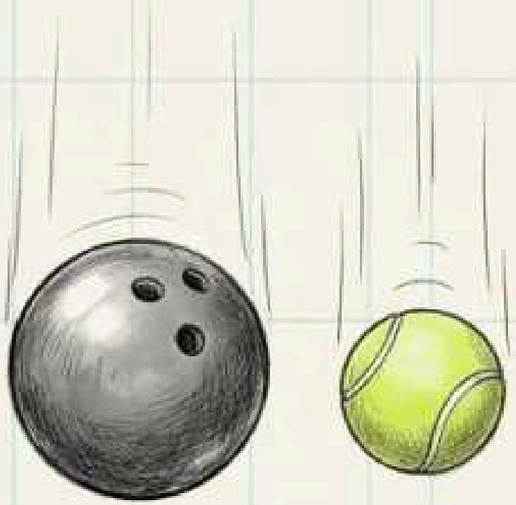
- Falling objects do not speed up forever in air.
- Air resistance grows until it balances the pull of gravity. Acceleration drops to zero.
- Steady speed = Terminal Velocity (50 to 60 m/s for a belly-down skydiver).
- Parachutes increase drag so terminal velocity becomes small enough to land.

Lecture Question

Vacuum

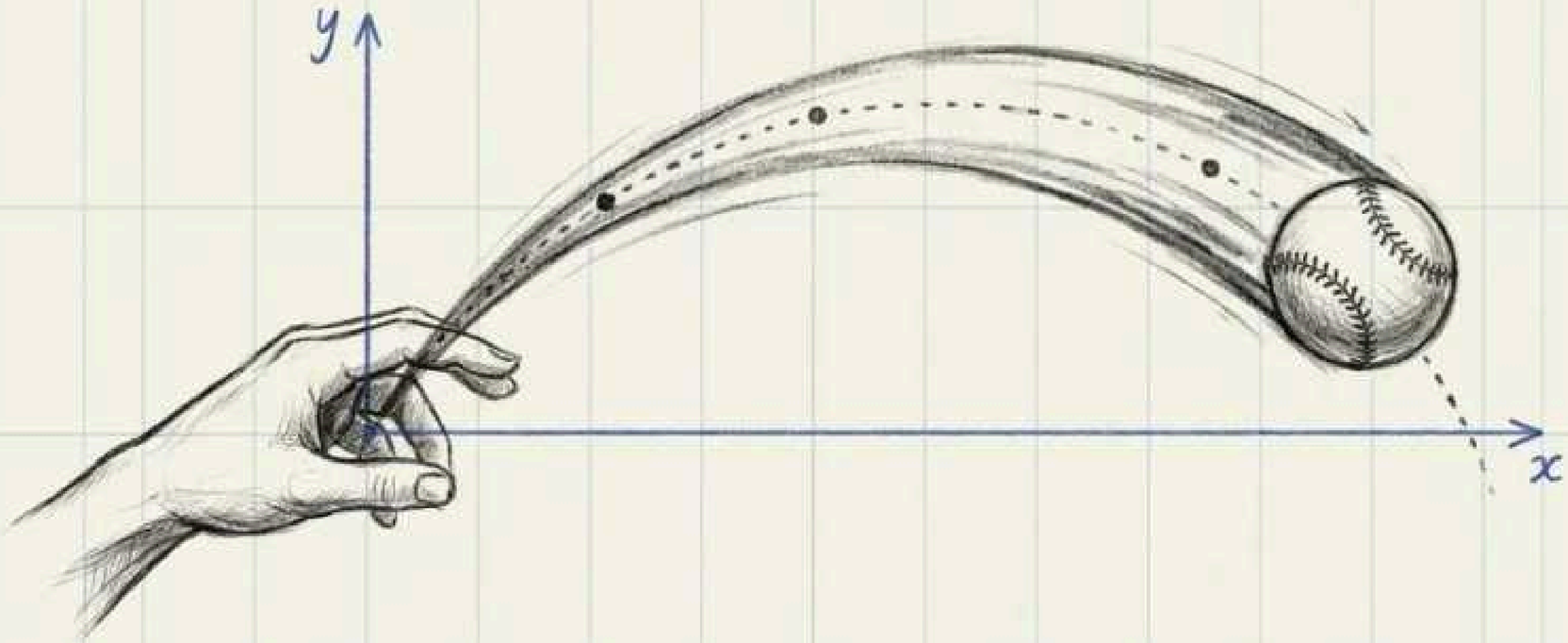


Air



A friend says a heavy bowling ball must hit the ground before a tennis ball dropped the same height. Using what you learned, how would you explain why, in a vacuum, they land together? And why, in air, might they land at slightly different times?

Coming Next: Motion in Two Dimensions



In lecture three, we add directions. Discovering how to *describe motion in two dimensions*, including the complete flight of a thrown ball.