Why do Seatbelts Save Lives?

Understanding Motion & Newton's Laws of Motion

Learning Objectives

Distance & Displacement

Distinguish between how far and how much change in position.

Speed & Velocity

Grasp the difference between scalar and vector measurements of motion.

Acceleration & Graphs

Understand acceleration and interpret various motion graphs.

Newton's Laws

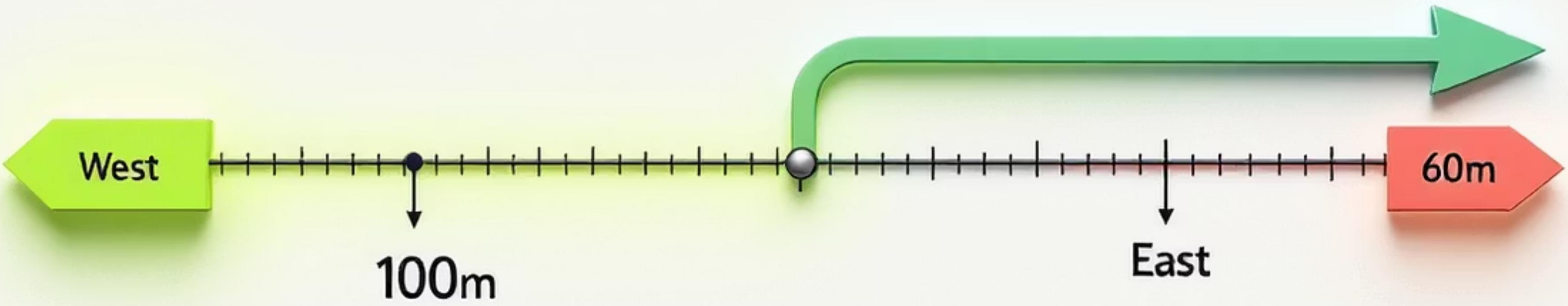
State and apply Newton's Three Laws of Motion.

Free-Body Diagrams

Learn to draw diagrams to analyze forces.

Real-World Problems

Solve practical physics problems using learned concepts.



Quick Think!

A cyclist moves 100m East, then 60m West in a total of 40 seconds.

- What is the total **Distance** travelled?
- What is the total **Displacement**?
- What is the average **Speed**?
- What is the average **Velocity**?

Distance vs. Displacement

Distance

How much ground an object has *actually* covered. (Scalar - only magnitude)

- **Example:** The cyclist's path length (100m + 60m = 160m).

Displacement

The object's overall *change in position*. (Vector - magnitude and direction)

- **Example:** The cyclist's straight-line distance from start to finish (40m East).

Distance

Displacement

Speed vs. Velocity

1

Speed

How fast an object is moving. (Scalar)

- **Formula:** Speed = Distance / Time

2

Velocity

How fast an object is moving *and in what direction.* (Vector)

- **Formula:** Velocity = Displacement / Time

Constant speed doesn't always mean constant velocity!

(e.g., driving in a circle)

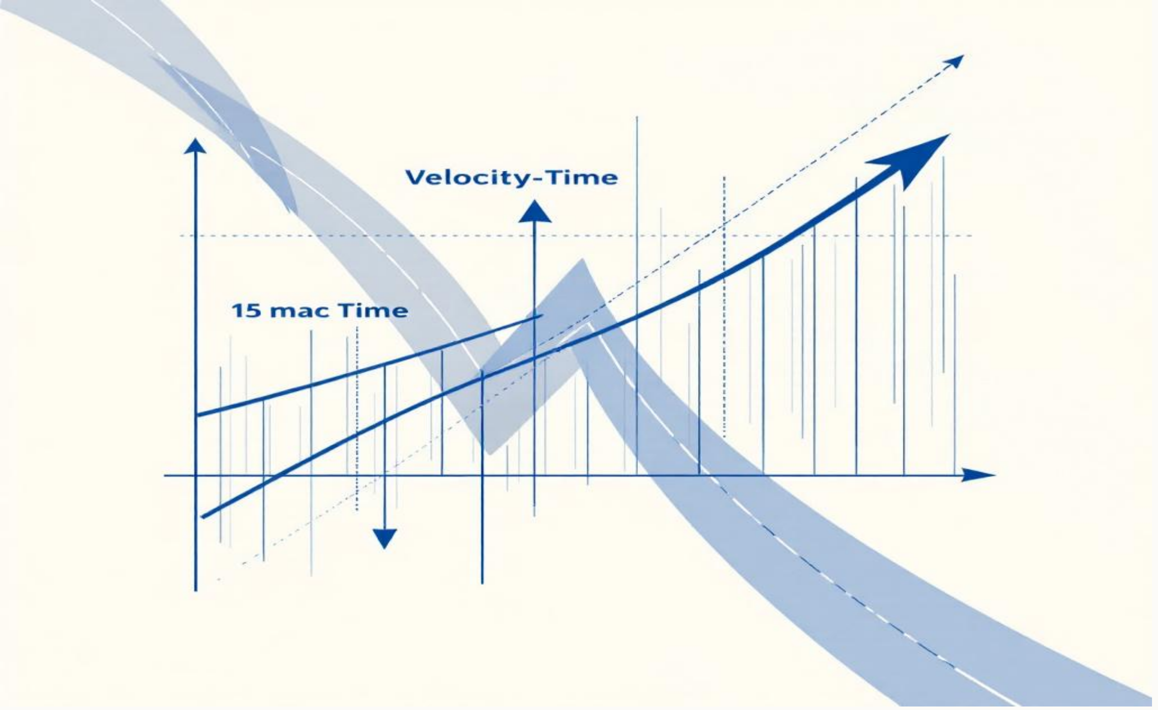
The Rate of Change: Acceleration

Acceleration is the rate at which an object's velocity changes over time. Remember, velocity is both speed and direction, so acceleration can mean speeding up, slowing down, or even just changing direction!

- It's a **vector quantity**, meaning it has both magnitude (how much) and direction.
- Its standard units are **meters per second squared (m/s²)**.

We can calculate acceleration using the following formula:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_{final} - v_{initial}}{t_{final} - t_{initial}}$$



Positive Acceleration (+a)

Indicates speeding up in the positive direction (e.g., accelerating forward) or slowing down in the negative direction.

Negative Acceleration (-a)

Often called **deceleration**. It means slowing down in the positive direction (e.g., braking) or speeding up in the negative direction (e.g., accelerating backwards).

Classifying Motion: Uniform vs. Non-Uniform

1

Uniform Motion

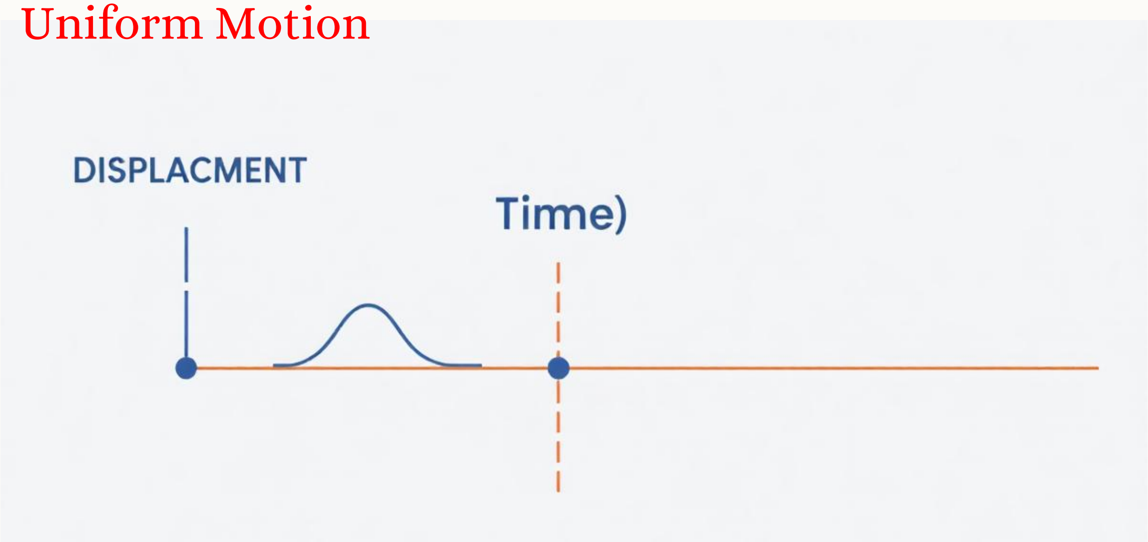
- **Definition:** Equal displacements in equal intervals of time.
- **On a Graph:** A straight-line **Position-Time (s-t) graph**.
- **Implication:** Constant velocity (steady speed and direction).

2

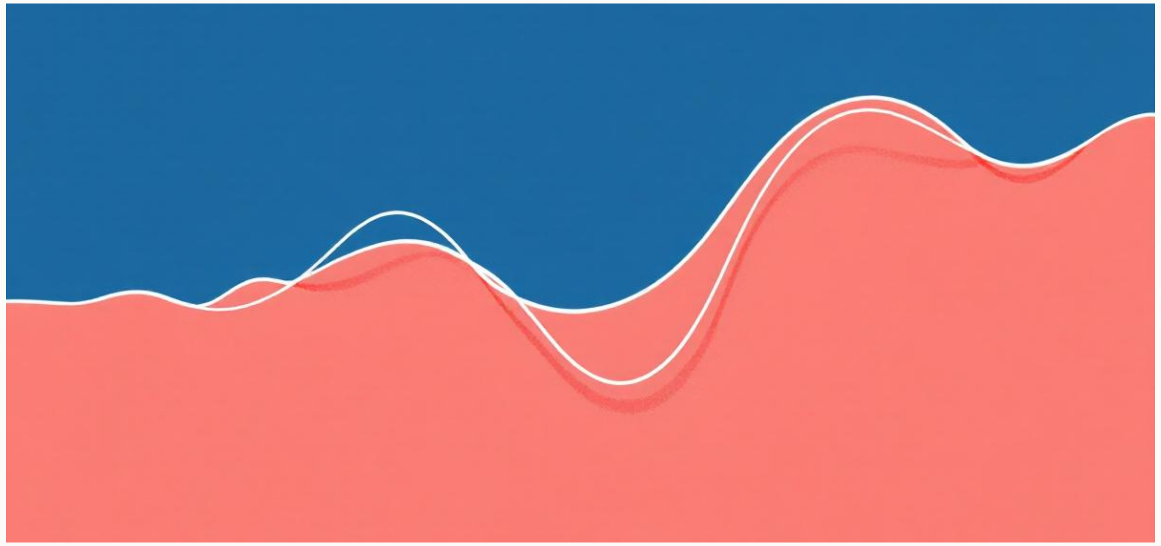
Non-Uniform Motion

- **Definition:** Unequal displacements in equal intervals of time.
- **On a Graph:** A curved **Position-Time (s-t) graph**.
- **Implication:** Changing velocity (acceleration or deceleration is occurring).

Uniform Motion



Non Uniform Motion



🤔 30-Second Challenge!

Which of the two graphs above represents an object that is accelerating? Point to the correct graph now!

Decoding the s-t Graph

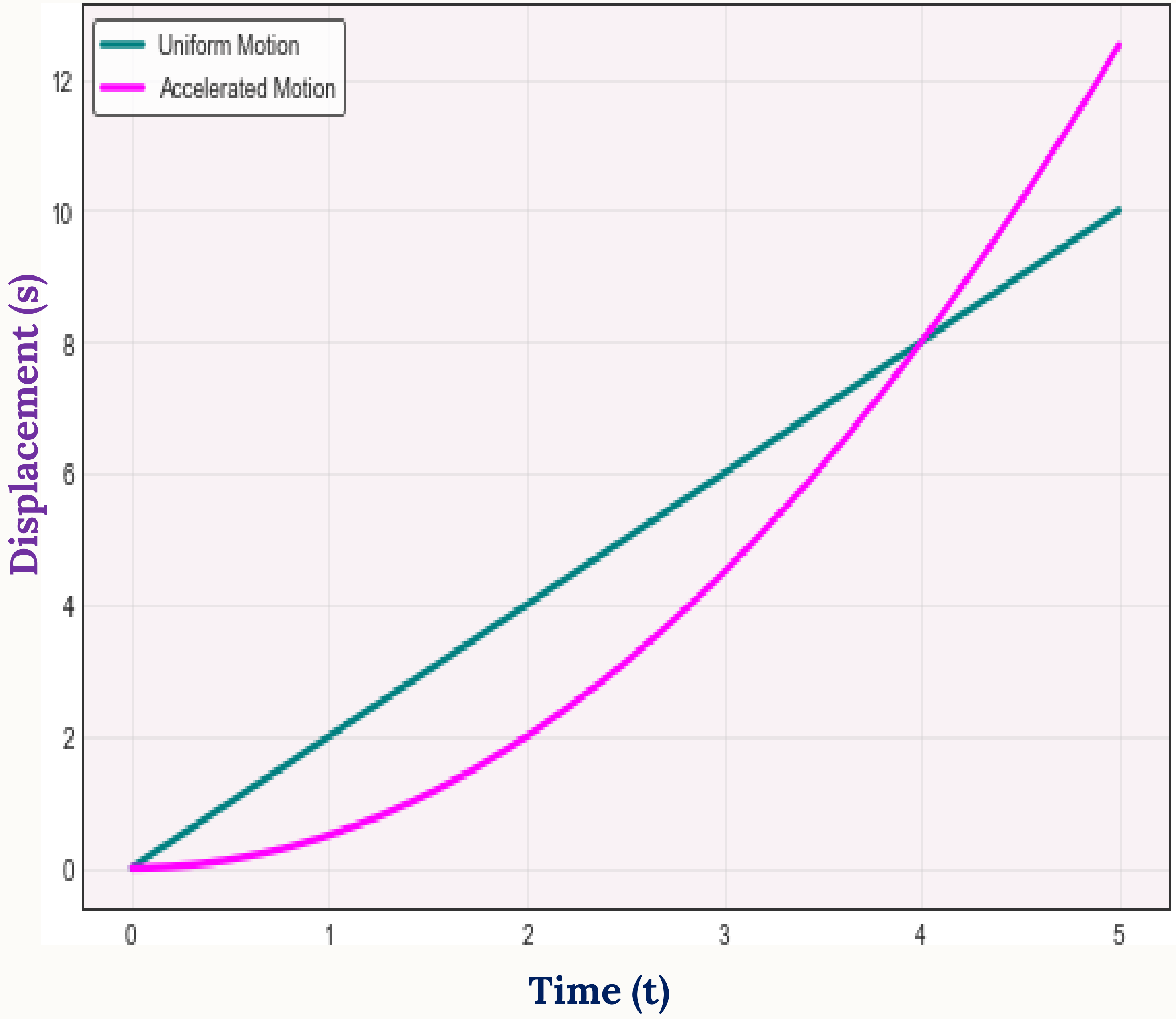
- The **slope** of the graph at any point equals the **velocity**.
- **Steeper slope** = Higher speed.
- **Flat/Horizontal line** (slope = 0): Object is **stationary** (v = 0).
- **Downward slope**: **Negative velocity** (moving back towards origin).

Task: Your Turn!

Look at the graph. What is the velocity at:

- t = 2 s? (~ +2.5 m/s)
- t = 5 s? (-5 m/s)

Displacement-Time Graph



The Power of the v-t Graph

1

Slope = Acceleration

$a = \Delta v / \Delta t$

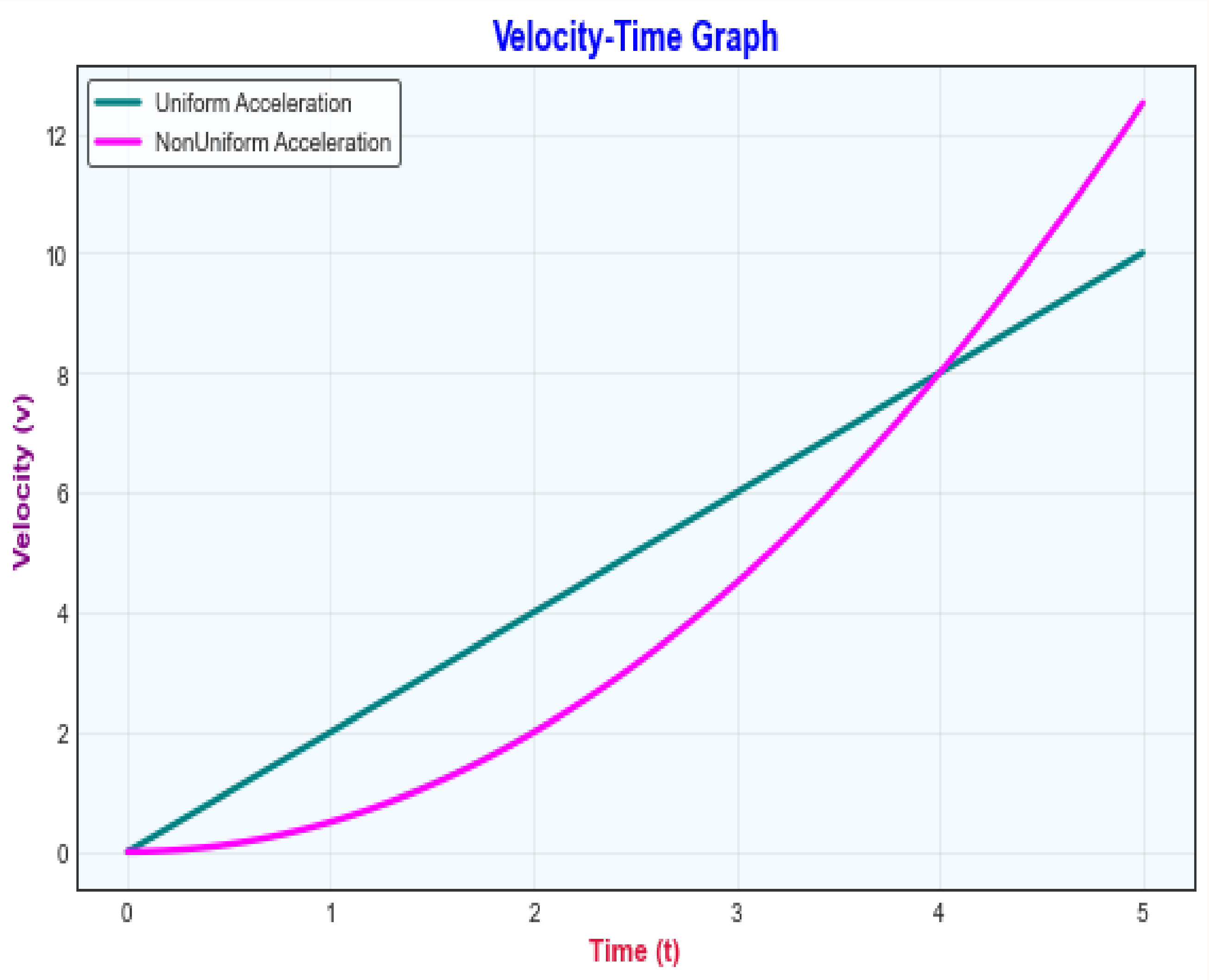
2

Area = Displacement

Area above time axis: Positive displacement

Area below time axis: Negative displacement

This graph is a powerhouse. Not only does its slope tell us about acceleration, but its area gives us the displacement. For constant acceleration, the area equals **$s = ut + \frac{1}{2}(at^2)$.**



The a-t Graph: Finding Δv

The area under an acceleration-time graph equals the change in velocity (Δv). Zero area means no change in velocity, so velocity remains constant.

1

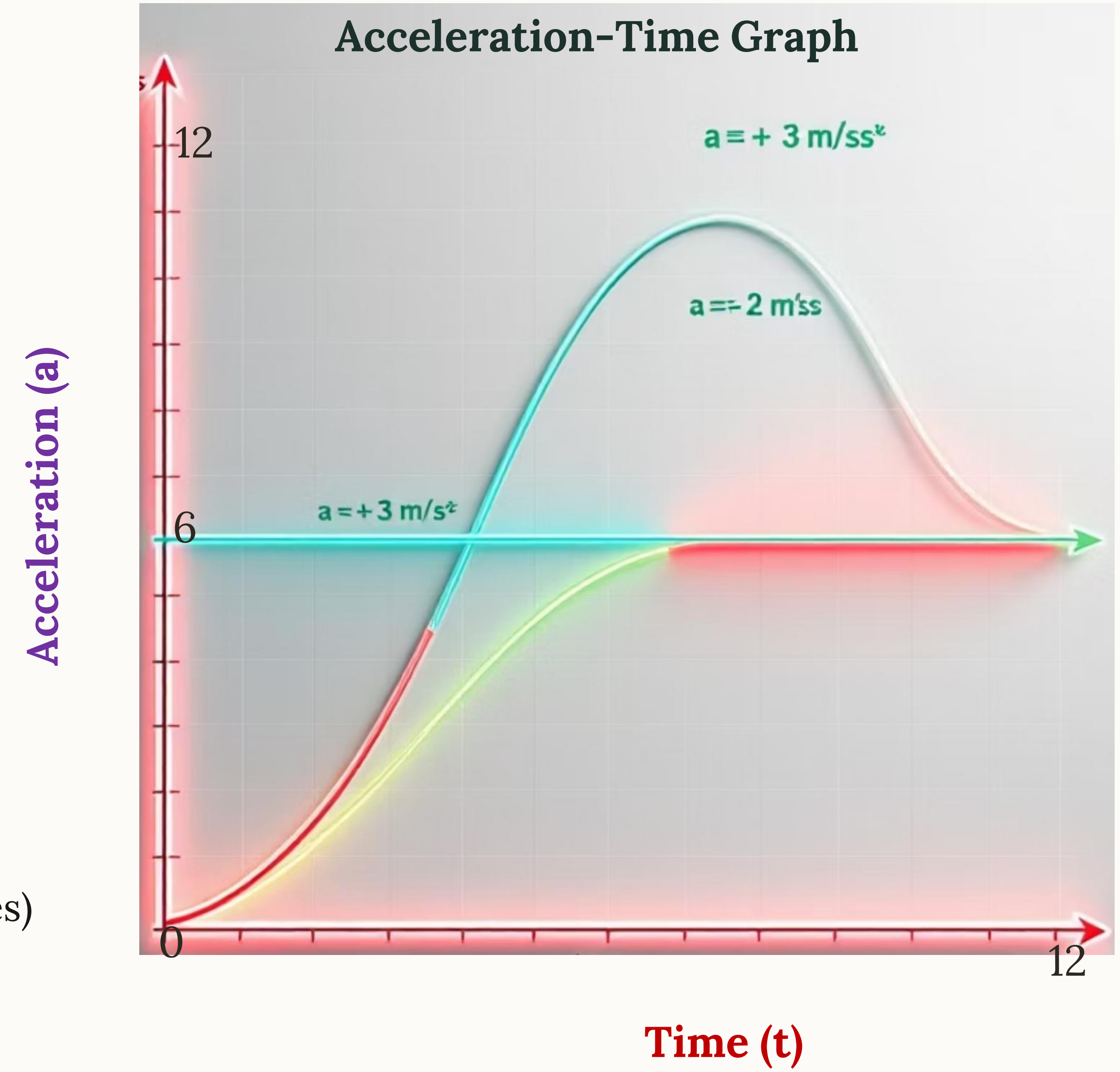
Area under graph = change in velocity

$\Delta v = \int a\,dt$

- Area above time axis: Positive velocity
- Area below time axis: Negative Velocity
- **Flat/Horizontal line** (slope = 0): (v = constant).

2

- **Uniform acceleration** → horizontal straight line (constant value).
- **Non-uniform acceleration** → sloping/irregular curve (changing values)



The Toolkit for Constant Acceleration

Three Kinematics equations

$v = u + at$

Final velocity equals initial velocity plus acceleration × time

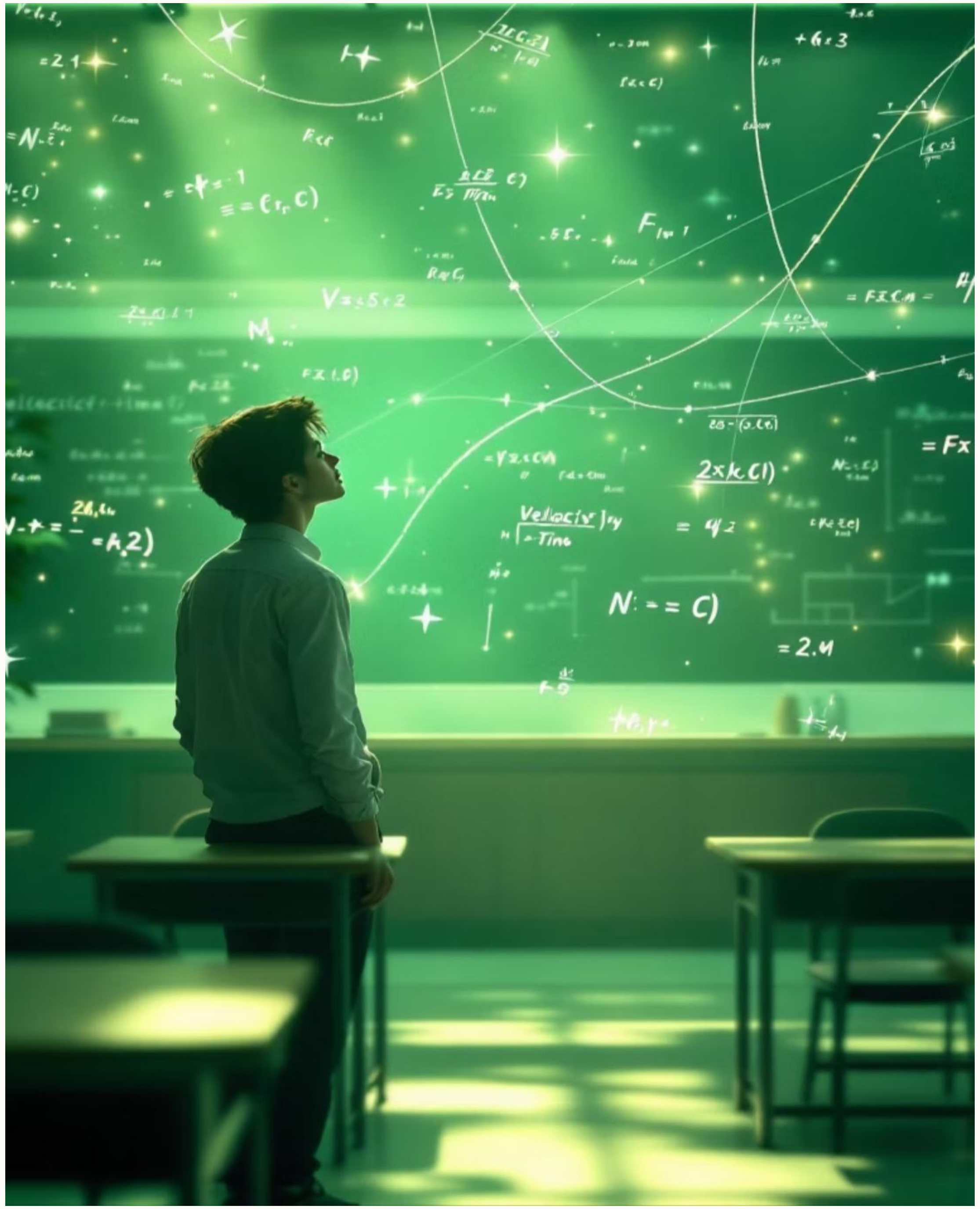
$s = ut + \frac{1}{2}(at^2)$

Displacement equals initial velocity × time plus half acceleration × time squared

$v^2 = u^2 + 2as$

Final velocity squared equals initial velocity squared plus twice acceleration × displacement

Important: These equations are only valid for motion with constant acceleration in a straight line.



Where does $v = u + at$ come from?

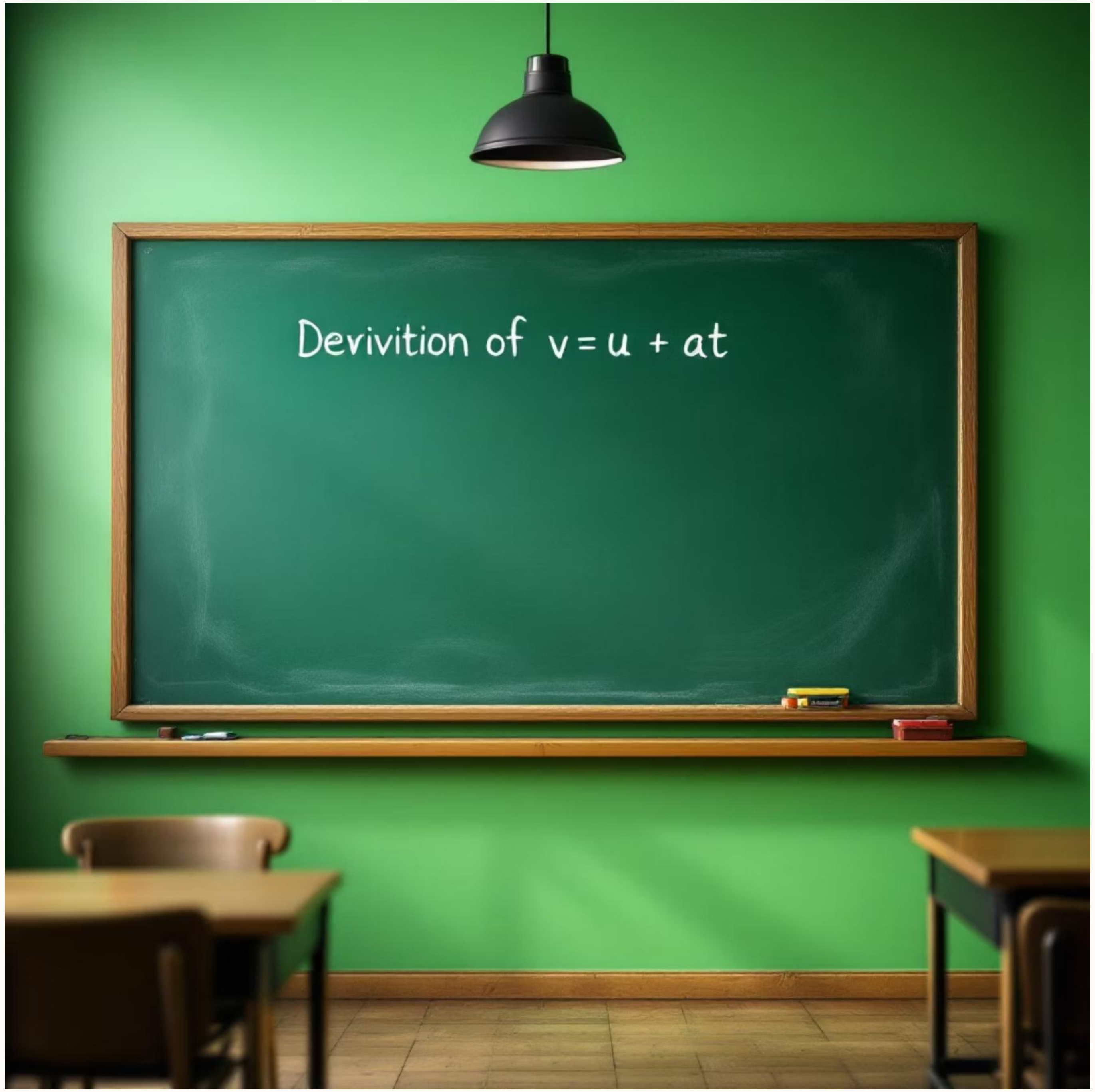
It comes straight from the definition of acceleration:

- Acceleration = Change in Velocity / Time
- $a = (v - u) / t$

Now, solve for v:

- $a \times t = v - u$
- $v = u + a \times t$

This is the most intuitive equation. It simply states that the final velocity equals the initial velocity plus whatever change $(a \times t)$ you added.



Deriving $s = ut + ½(at^2)$

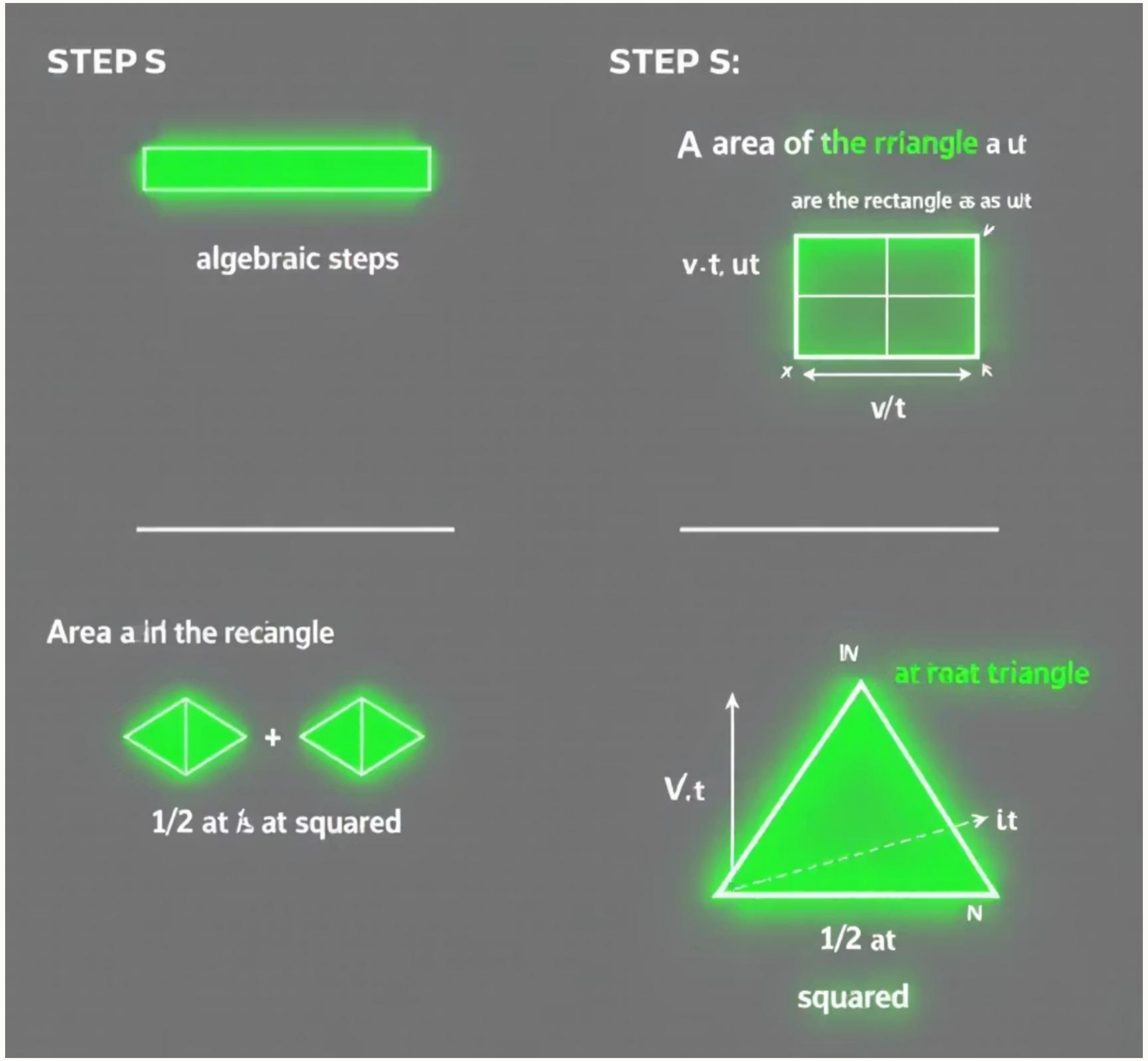
For constant acceleration, average velocity is the midpoint:

- $v\_avg = (u + v) / 2$
- Displacement = Average Velocity × Time
- $s = v\_avg \times t = [(u + v) / 2] \times t$

Substitute $v = u + at$:

- $s = [(u + (u + at)) / 2] \times t$
- $s = [(2u + at) / 2] \times t$
- $s = ut + ½at^2$

The graphical proof is the most beautiful—it shows the equation literally represents the area under the v-t curve.



Deriving $v^2 = u^2 + 2as$

Start with our first two equations

1. $v = u + at \rightarrow t = (v - u)/a$

2. $s = ut + \frac{1}{2}at^2$

Substitute equation (1) for t into equation (2)

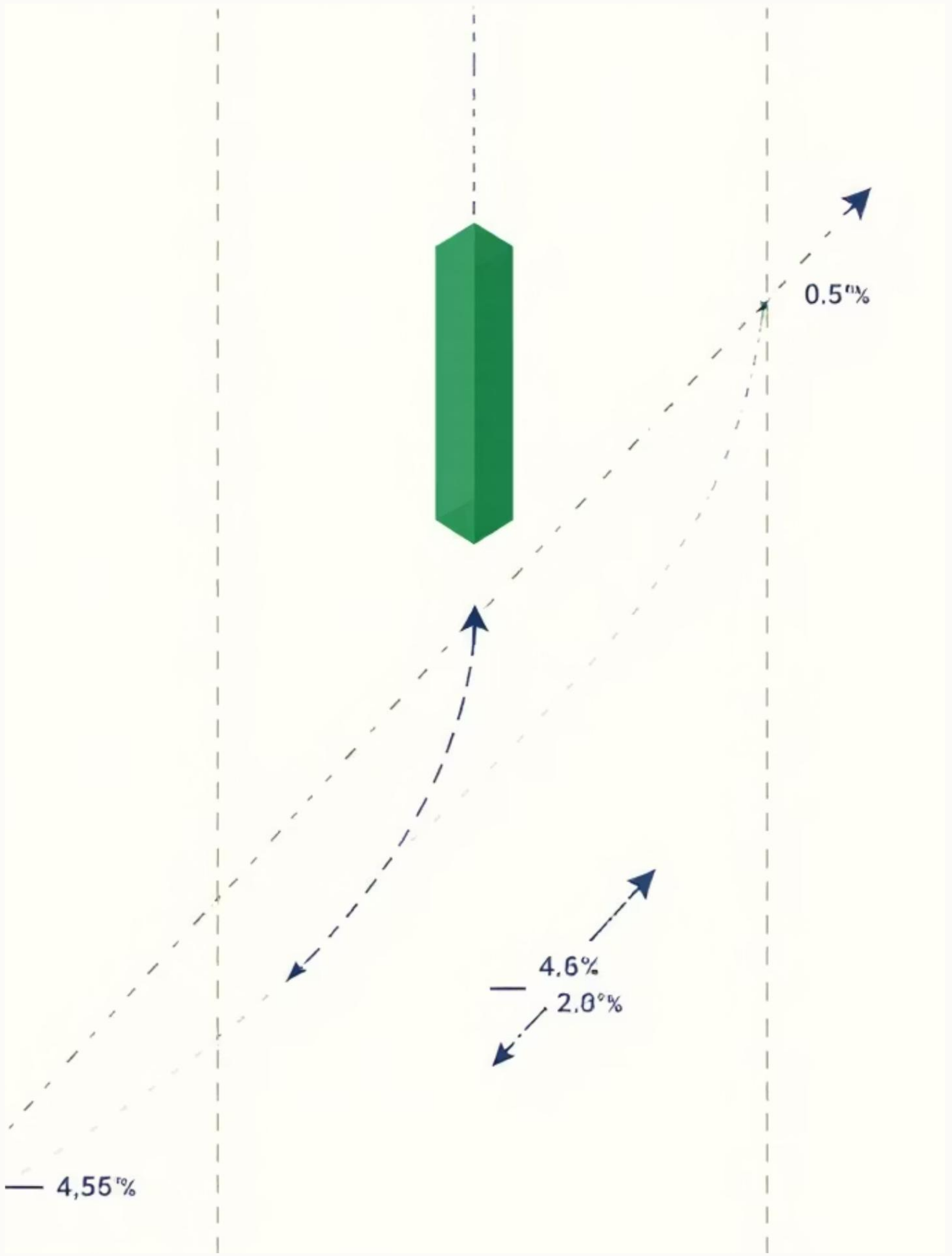
$$s = u[(v - u)/a] + \frac{1}{2}a[(v - u)/a]^2$$

Simplify and rearrange

$$2as = v^2 - u^2$$

$$v^2 = u^2 + 2as$$

This derivation gives us an equation that relates velocity, acceleration, and displacement without needing to know time.



Free Fall: Motion under Gravity

- Acceleration due to gravity (g): ≈ 9.8 m/s^2 downward near Earth's surface
- Choosing axes is key! If up is positive: Acceleration $a = -g = -9.8\ m/s^2$
- We ignore air resistance for now

Example: Ball thrown upward at 20 m/s

Time to reach max height?

- Use $v = u + at$. At top, $v = 0$
- $0 = 20 + (-9.8) \times t \rightarrow t \approx 2.04$ s

Maximum height?

- Use $v^2 = u^2 + 2as$
- $0^2 = 20^2 + 2 \times (-9.8) \times s \rightarrow s \approx 20.4$ m

Let's Solve a Problem

Problem:

A car starts from rest and accelerates at 3 m/s^2 for 5 seconds.

Find:

- (a) its final velocity
- (b) its displacement

Known:

$u = 0$ m/s, $a = 3$ m/s^2, $t = 5$ s

Solution:

(a) Find v: $v = u + at$

$v = 0 + (3)(5) = 15$ m/s

(b) Find s: $s = ut + \frac{1}{2}at^2$

$s = (0)(5) + \frac{1}{2}(3)(5)^2 = 0 + \frac{1}{2}(3)(25) = 37.5$ m

Cross-check with v-t graph area:

Area = ½ × base × height = ½ × 5 s × 15 m/s = 37.5 m ✓

From Description to Explanation: The Role of Forces

Kinematics: The "What"

Describes motion using concepts like displacement, velocity, and acceleration

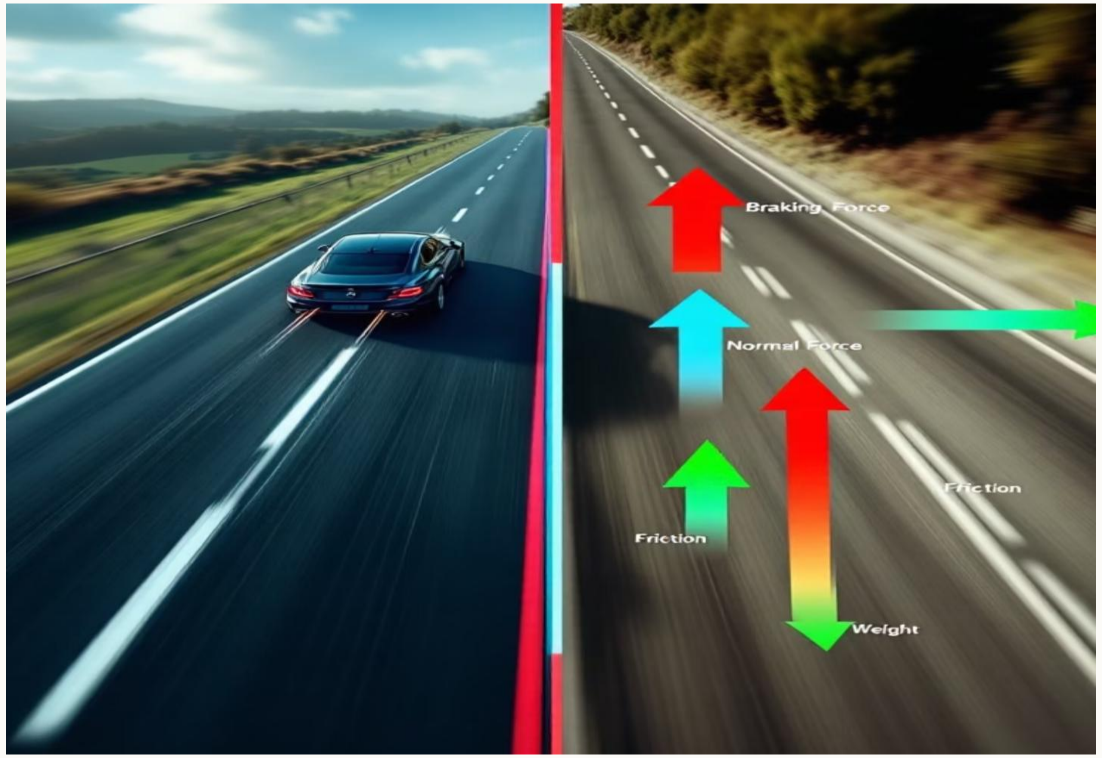
Dynamics: The "Why"

Explains why motion changes through the study of forces

The Bridge

Forces are the pushes and pulls that cause acceleration ($a = F_{net} / m$)

We've spent time describing motion. Now we ask the fundamental question: what causes it to change? The answer is forces. This bridges our two main units.



Newton's First Law: The Law of Inertia

"An object at rest stays at rest, and an object in motion stays in motion with the same velocity, unless acted upon by a net external force."

Understanding Inertia

- **Inertia:** An object's natural resistance to changes in its state of motion.
- **Mass:** The quantitative measure of inertia – more mass means more inertia.

Real-World Examples:

- Passengers lurching forward when a car suddenly brakes.
- Dust flying off a carpet when beaten, as the dust resists moving with the carpet.

Don't Mix These Up: Mass vs. Weight

Mass (m)	Weight (W)
Amount of matter	Force of gravity on mass
Scalar (kg)	Vector (N)
Constant everywhere	Depends on gravity (W = m * g)
Measured with a balance	Measured with a spring scale

True or False? "Your mass changes if you go to the Moon."

Answer: **FALSE**. Your mass remains constant. Only your weight changes (it's about 1/6th of your Earth weight!).

Newton's Second Law: F_net = m * a

$$\Sigma F = m * a$$

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

- **$\Sigma F = m * a$** (For constant mass)
- **Direction:** Acceleration always aligns with the direction of the net force.

- **Unit:** 1 Newton (N) = 1 $kg \cdot m/s^2$.
- **Advanced Note:** More generally, **$\Sigma F = dp/dt$**, (For Variable mass) where momentum $p = m * v$.

Newton's Third Law: Action-Reaction Pairs

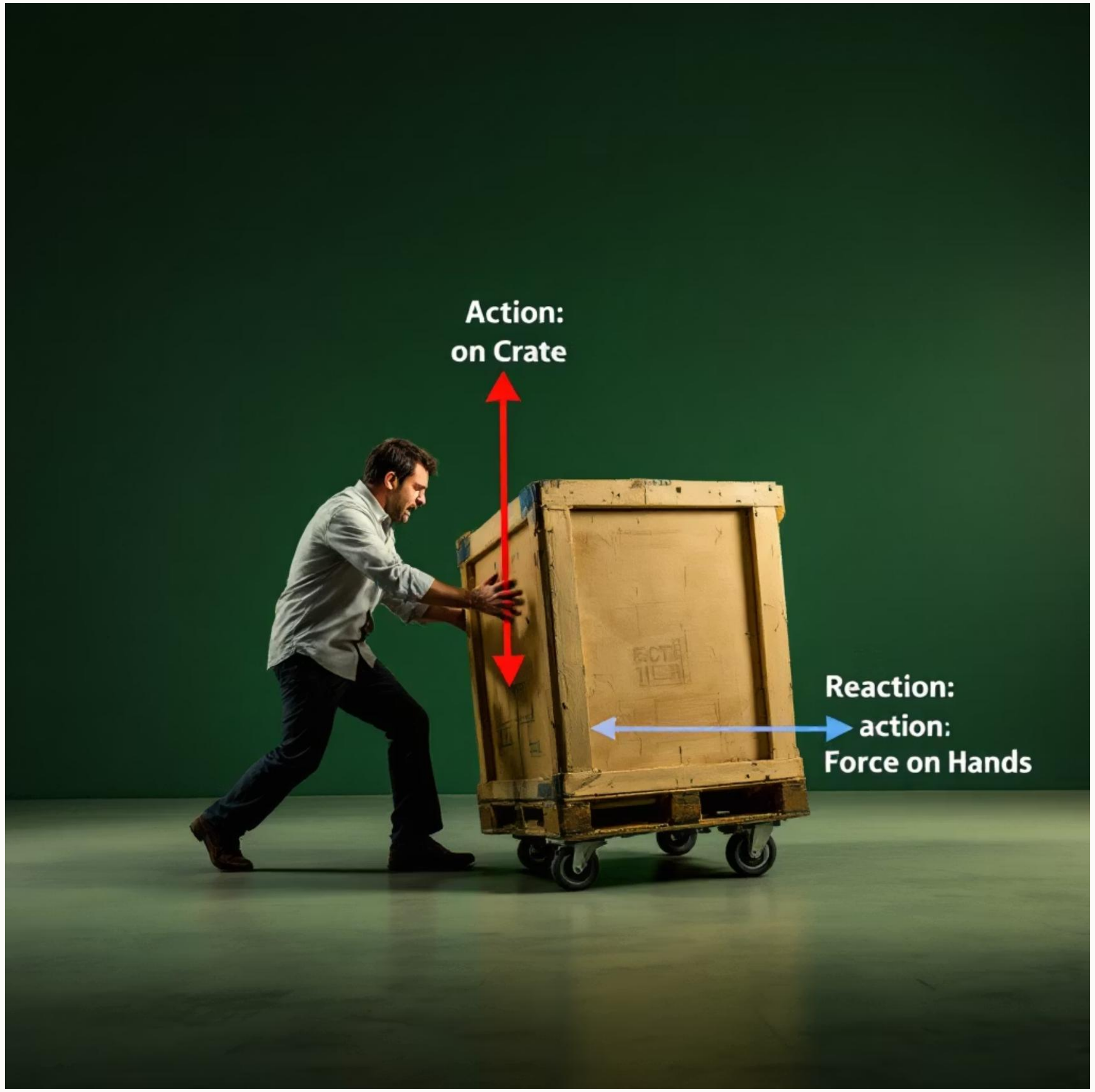
"For every action force, there is an equal and opposite reaction force."

The Key: These two forces always act on **two different objects**.

- **Example:** When you push on a wall (action force **on the wall**), the wall simultaneously pushes back on you (reaction force **on you**).

Common Pitfalls to Avoid:

- Normal force is not always equal to weight (e.g., in an elevator).
- Action-reaction forces don't cancel each other out because they act on different objects and thus cannot be added in a single Free-Body Diagram.



Free-Body Diagrams (FBDs): Your Essential Tool

1. Isolate the Object

Represent it as a single dot.

2. Identify All Forces

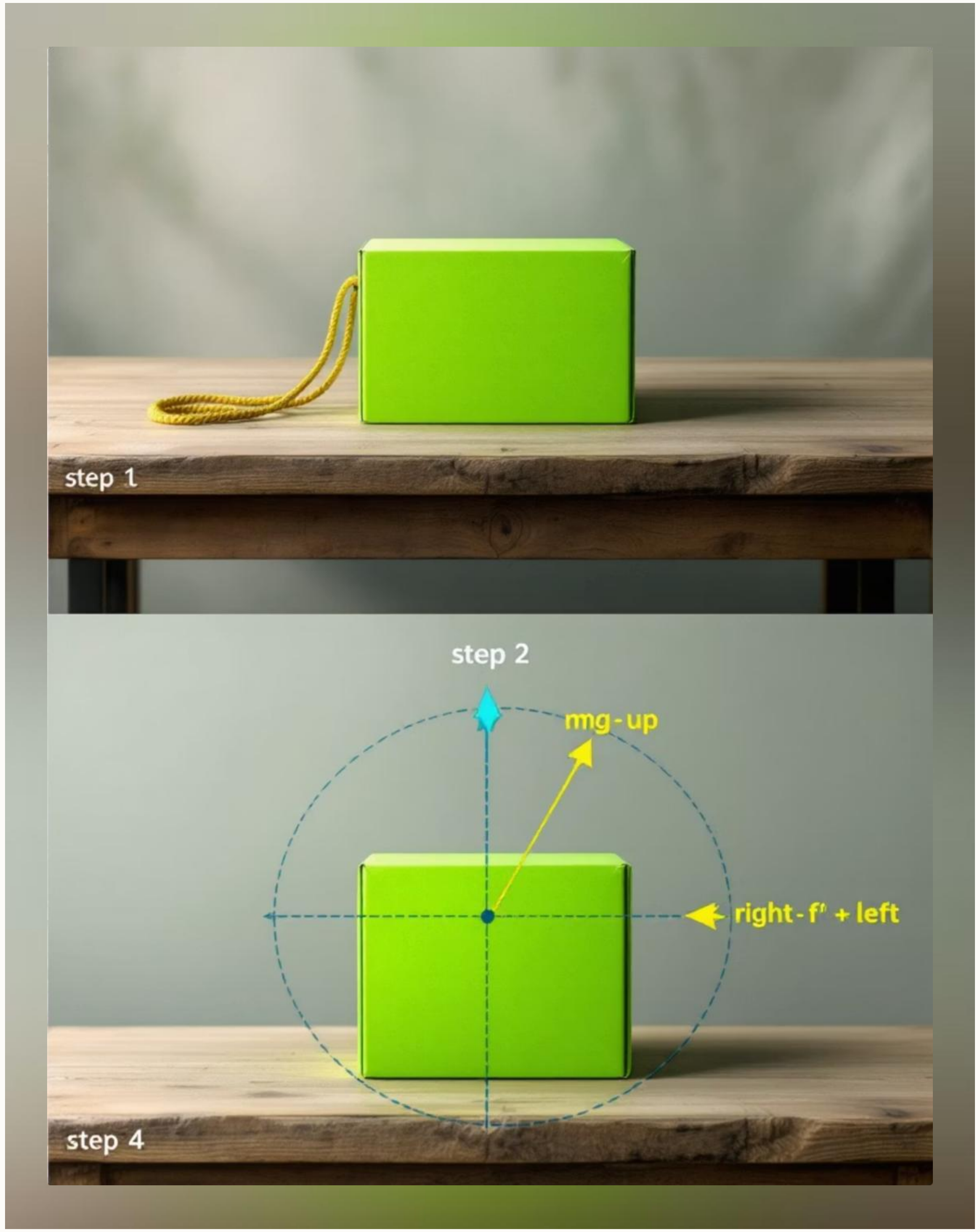
Draw labeled vector arrows from the dot (e.g., Weight (mg), Normal (N), Tension (T), Friction (f), Applied (F)). Remember, no forces the object exerts!

3. Draw Vector Arrows

Clearly label each force with its magnitude and direction.

4. Choose a Coordinate System

Align one axis with the direction of motion, if possible.



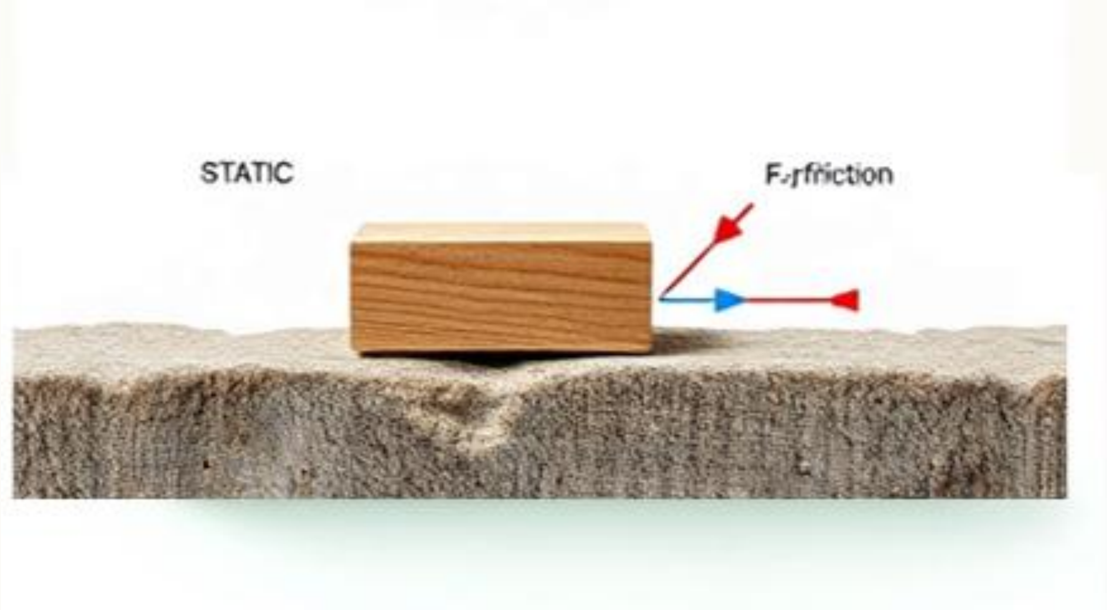
The Nature of Friction

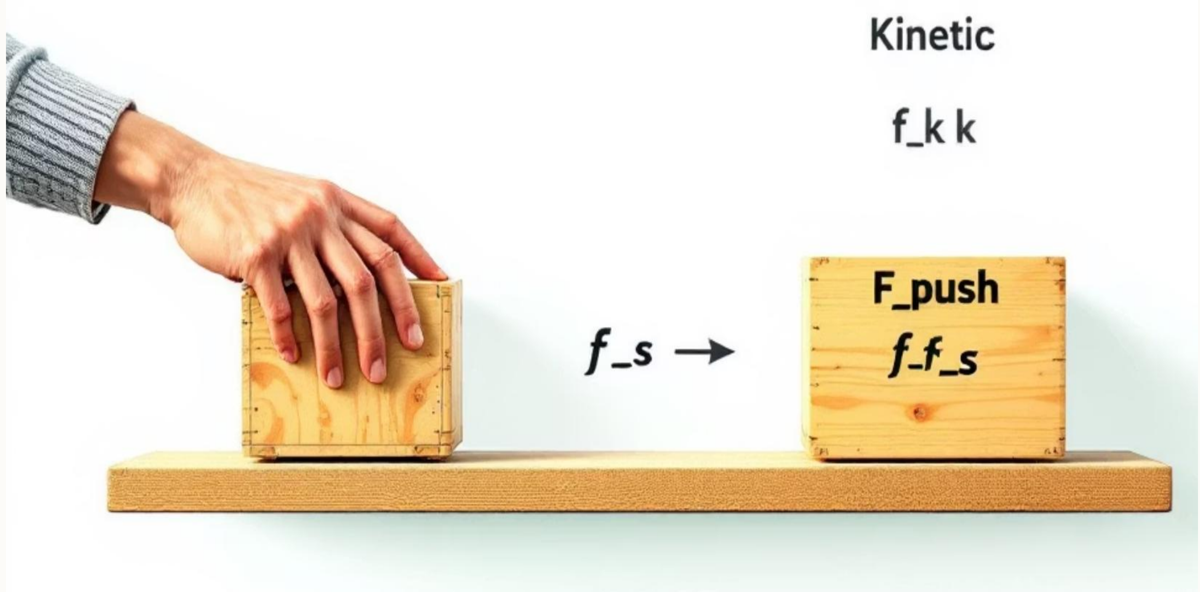
Static Friction (`f_s`)

- Prevents relative motion between surfaces.
- Adjusts to match applied force, up to a maximum: `f_s ≤ μ_s * N`.

Kinetic Friction (`f_k`)

- Acts when surfaces are sliding past each other.
- Is constant: `f_k = μ_k * N` (where `μ_k < μ_s`).





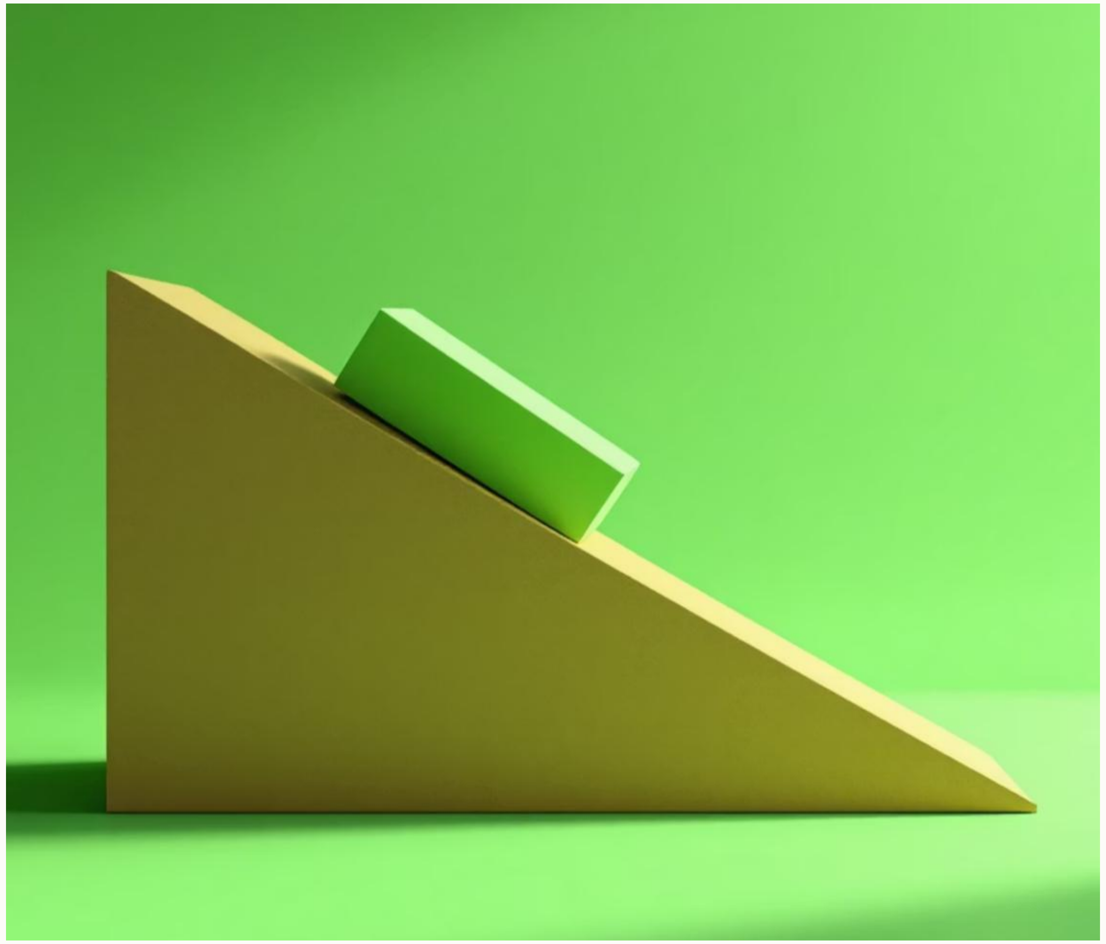
Direction: Always opposes relative motion or impending motion.

⚠ Misconception Alert:

"Friction always opposes motion." **False!** It opposes **relative motion.** When you walk, friction between your foot and the ground actually propels you forward.

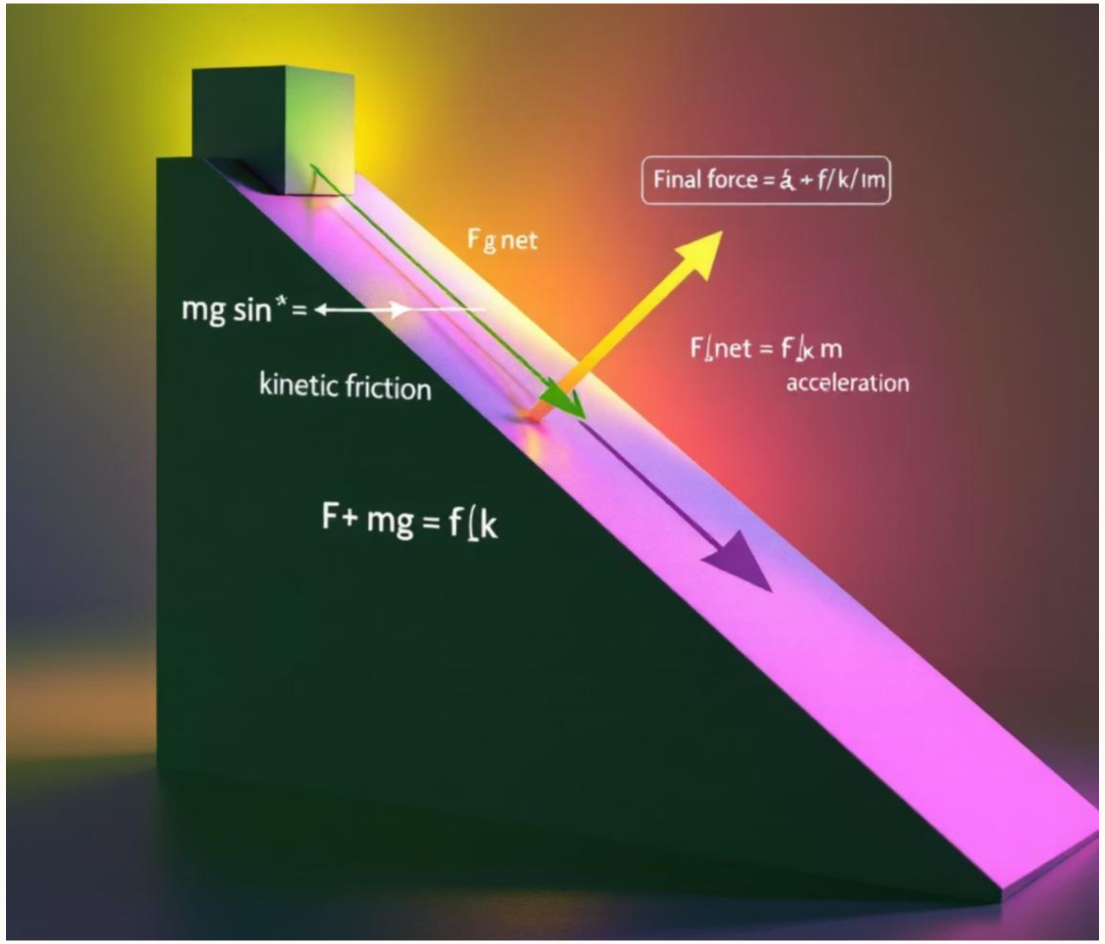
The Inclined Plane: Unlocking Complex Problems

Frictionless Ramp



- Forces: Gravity (mg) and Normal Force (N).
- Resolve mg: Parallel ($mg \sin\theta$) and Perpendicular ($mg \cos\theta$).
- Acceleration: $a = g \sin\theta$

With Friction



- Kinetic Friction (f_k) acts up the incline.
- Net Force Parallel: $\Sigma F_{parallel} = mg \sin\theta - f_k$
- Acceleration: $a = g (\sin\theta - \mu_k \cos\theta)$
- It slides if: $mg \sin\theta > \mu_s mg \cos\theta$

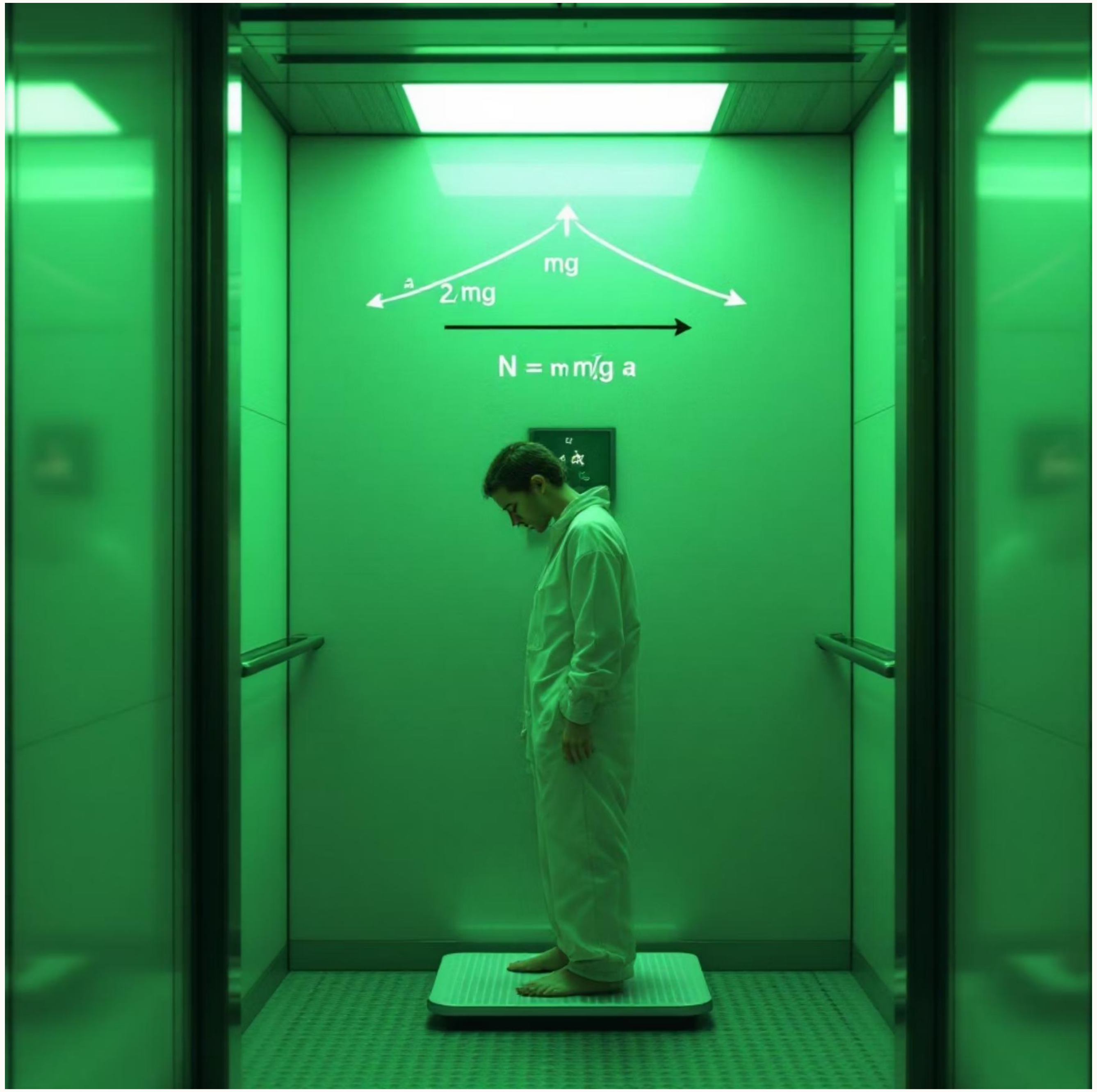
Apparent Weight: What the Scale Reads

Your apparent weight is equal to the normal force (N) supporting you. When you stand on a scale, it measures this normal force, not your actual weight (mg).

> **$\Sigma F_y = m\,a$** (Taking upward as positive)
>
> **$N - mg = m\,a \rightarrow N = m(g + a)$**

- **Accelerating Upwards ($a > 0$):** $N > mg$ (You feel heavier)
- **Accelerating Downwards ($a < 0$):** $N < mg$ (You feel lighter)
- **Free Fall ($a = -g$):** $N = m(g - g) = 0$ (Weightlessness!)

> ⓘ Quick Calculation:
>
> A 60 kg person accelerates up at 2 m/s^2.
>
> **$N = 60 * (9.8 + 2) = 60 * 11.8 = 708$ N** (vs. 588 N at rest)



The Atwood Machine

A classic system for applying **ΣF = ma** to multiple connected objects.

Assumptions:

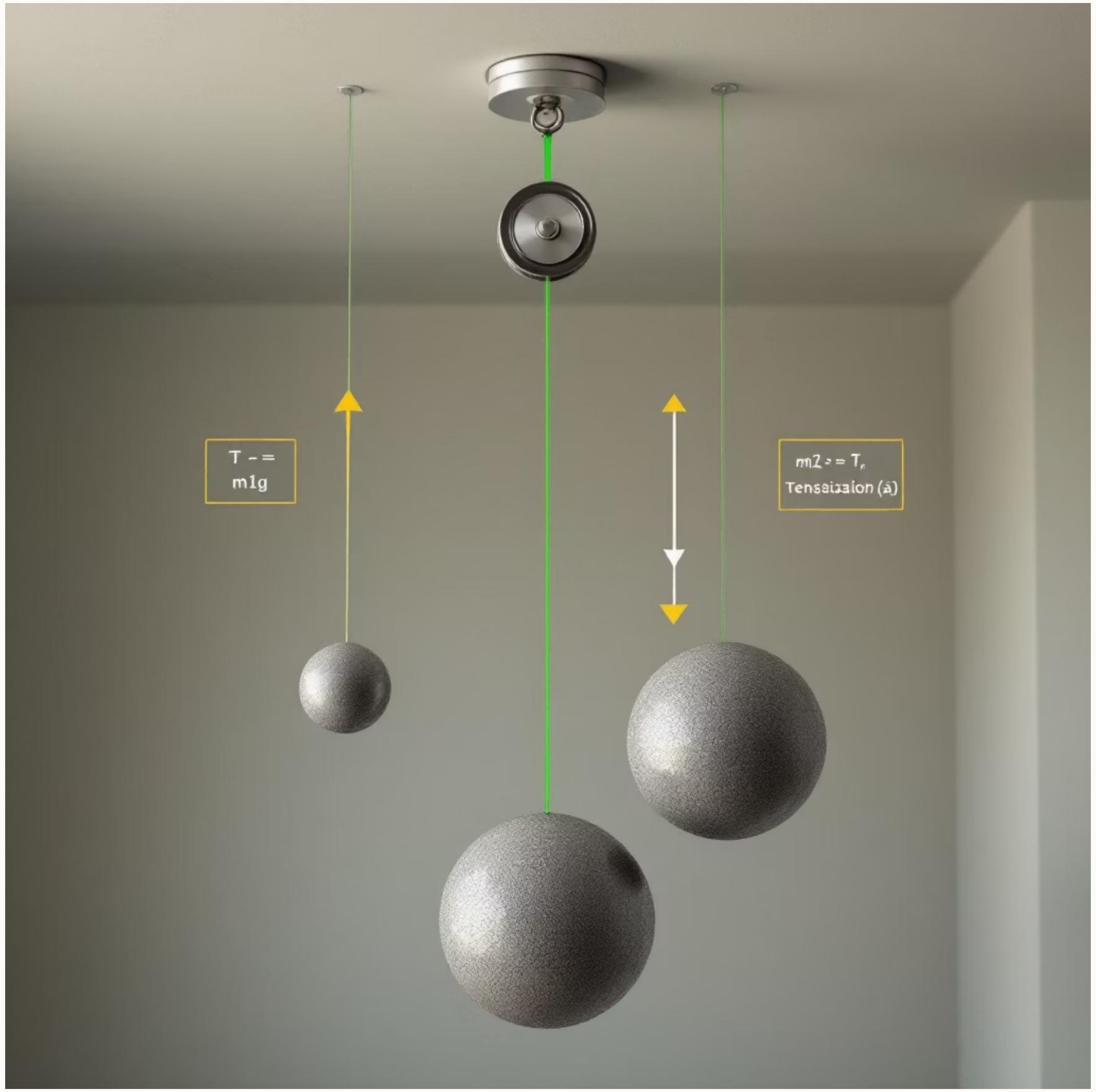
- Massless, frictionless pulley;
- Massless string.

Key Formulas:

- Acceleration Magnitude: $a = (m_2 - m_1)g / (m_1 + m_2)$
- Tension in String: $T = (2 m_1 m_2 g) / (m_1 + m_2)$

How to Solve:

1. Assume direction of acceleration (usually let heavier mass's direction be positive).
2. Draw Free Body Diagrams (FBD) for each mass.
3. Write $\Sigma F = ma$ for each mass.
4. Solve the system of equations.



> **Speaker Notes:**
>
> This setup is like a one-dimensional tug-of-war. The net force is the difference in weights, and the total mass being accelerated is the sum of both masses. The tension is not just the average of the weights!

Let's Bust Some Kinematics Myths!

Constant speed means no acceleration.	**False!** Changing direction (e.g., circular motion) requires acceleration.
Action-reaction forces cancel out.	**False!** They act on different objects. They never cancel each other.
The normal force always equals mg.	**False!** It equals mg only on horizontal surfaces with no other vertical forces. (Think elevators or pushes!)
Friction always opposes motion.	**False!** Static friction enables walking and car motion by providing the forward force.

Test Your Understanding!

1

1. Multiple Choice Question

A 2 kg block slides down a frictionless 30° incline. What is its acceleration?

- A) 4.9 m/s^2
- B) 9.8 m/s^2
- C) 0 m/s^2
- D) 19.6 m/s^2

Answer: A) $a = g \sin\theta = 9.8 * \sin(30°) = 9.8 * 0.5 = 4.9$ m/s^2

2

2. True/False

Action and reaction forces act on the same object.

Answer: FALSE. They act on two different interacting objects.

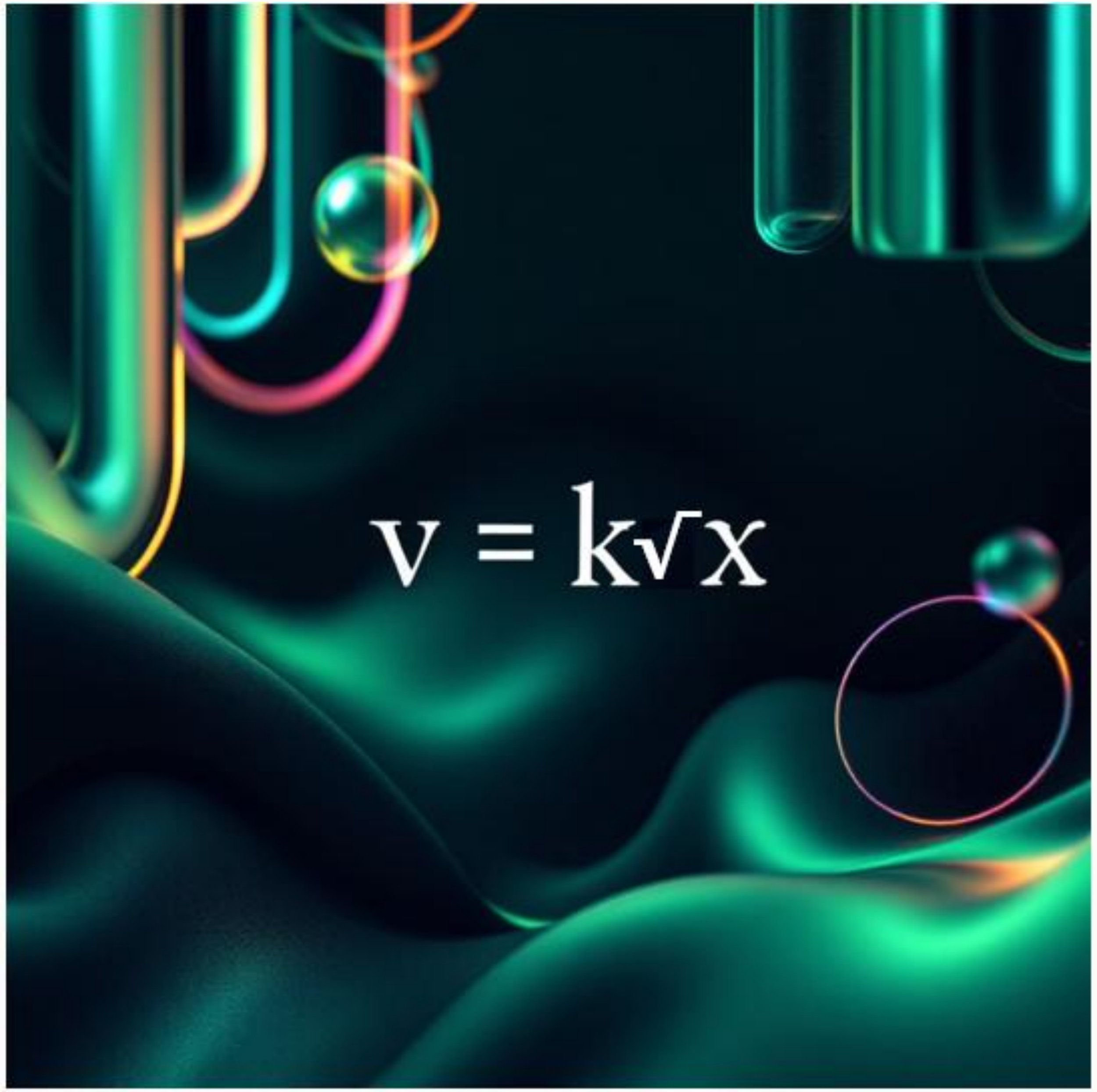
3

3. Open-Ended

Draw the FBD for a book being pushed at constant speed across a table. Why is the acceleration zero?

Answer: Forces: mg down, N up, F_{push} right, f_k left. Acceleration is zero because the net force is zero ($F_{push} = f_k$ and $N = mg$). Newton's First Law!

Advanced Challenge #1: Kinematics & Calculus



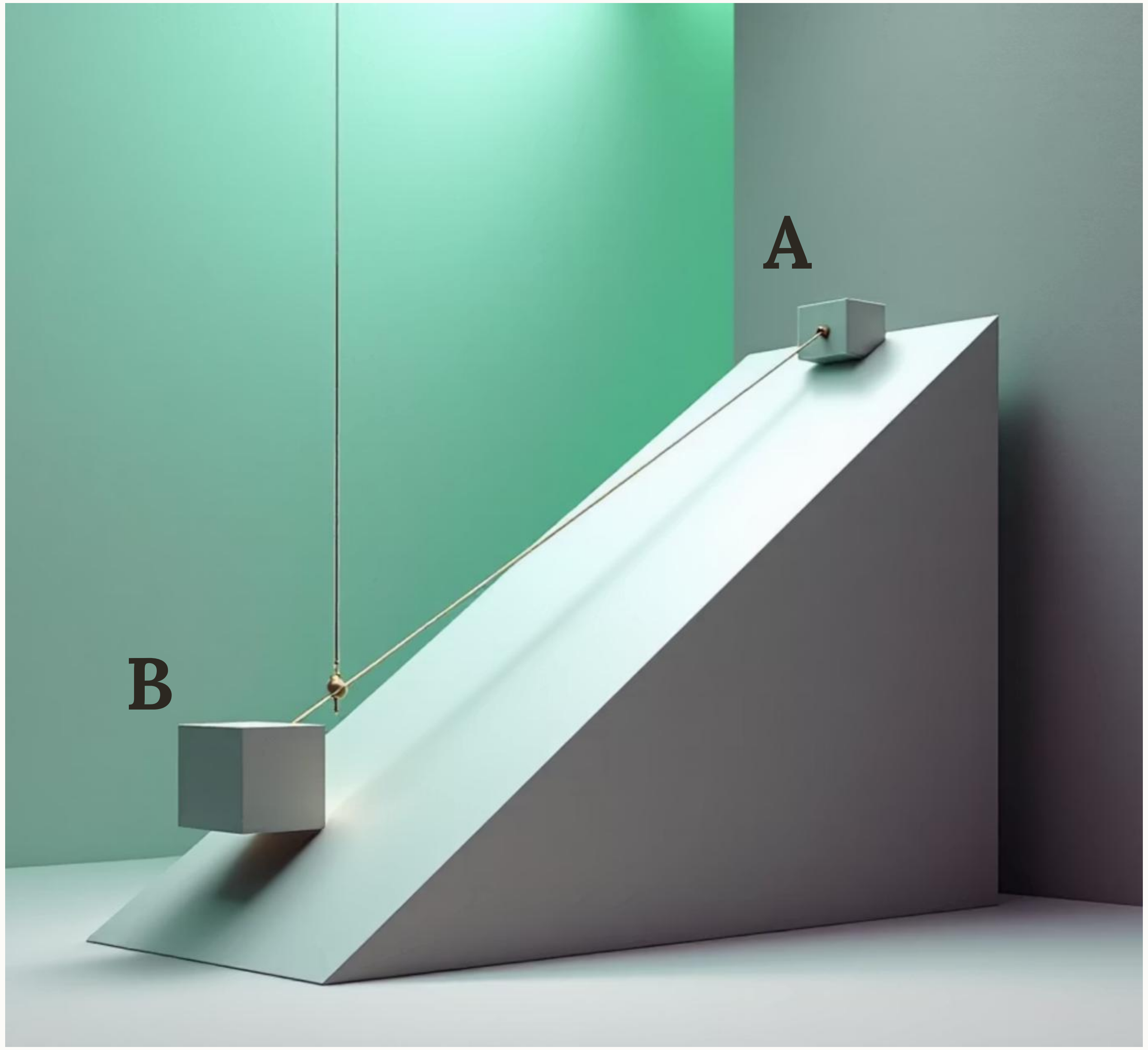
The velocity of a particle moving in one dimension is given **by $v = k\sqrt{x}$,** where k is a positive constant. Assuming the particle was at $x = 0$ at $t = 0$, find its:

- (a) Displacement as a function of time, $x(t)$.
- (b) Acceleration as a function of time, $a(t)$.
- (c) Average velocity in the first t seconds.

Hint:

This problem tests your understanding of non-uniform motion and the ability to use calculus in kinematics. Remember, $v = dx/dt$. This is a differential equation you need to solve.

Advanced Challenge #2: Relative Motion & Constraints

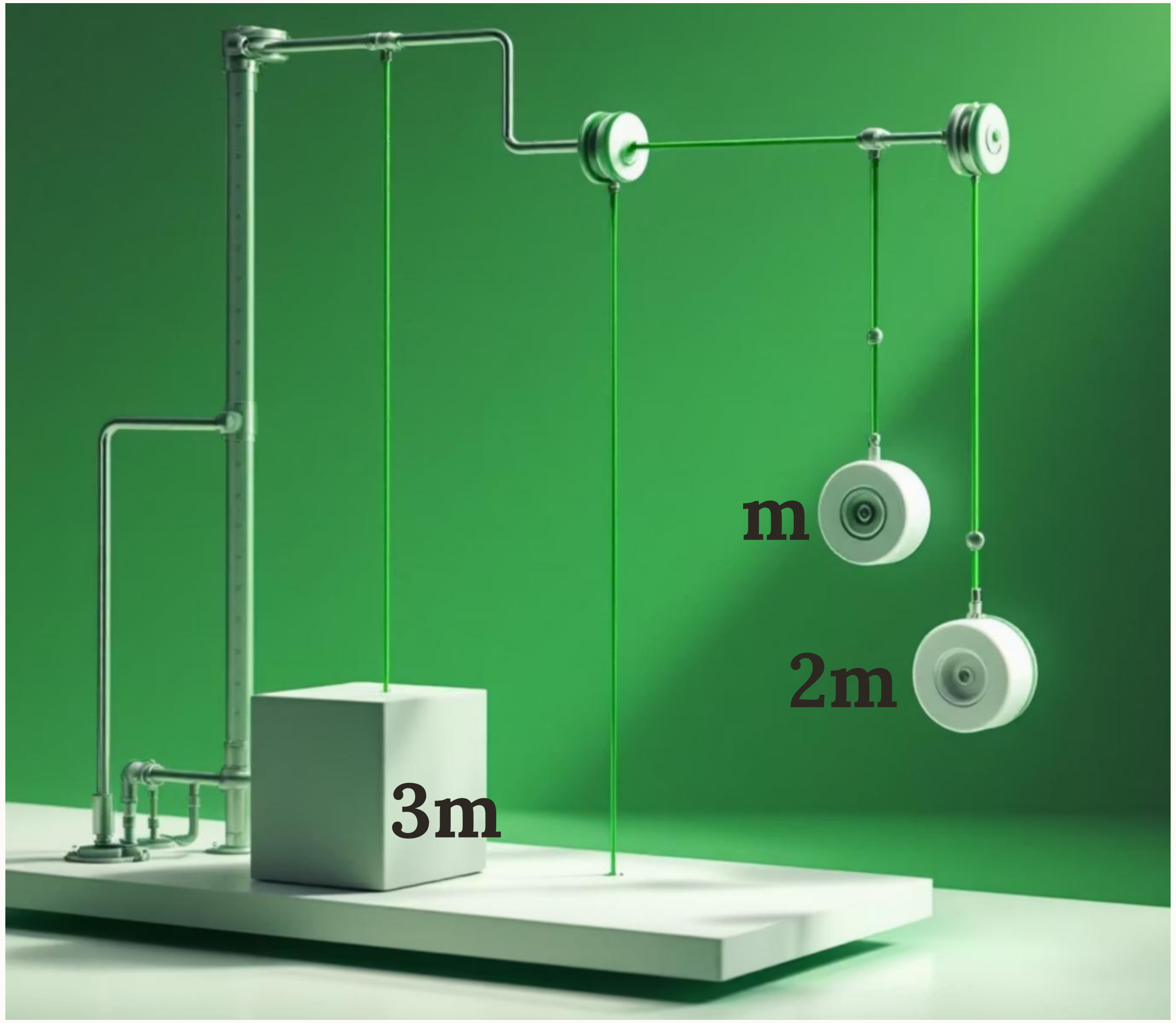


Find the relationship between the acceleration of block A (a_A) and the acceleration of wedge B (a_B) in the given configuration. Assume all surfaces are smooth and the pulley is massless and frictionless.

Key Insight:

This is a classic constrained motion problem. The key is to find the relative acceleration of A with respect to B and then apply the string constraint. The motion of the wedge itself adds a layer of complexity.

Advanced Challenge #3: System of Blocks & Pulleys



In the system shown, find the acceleration of mass C and the tension in the string connecting masses A and B. Assume all pulleys are massless and frictionless, and the table is smooth.

- **Mass of A** = m
- **Mass of B** = 2m
- **Mass of C** = 3m

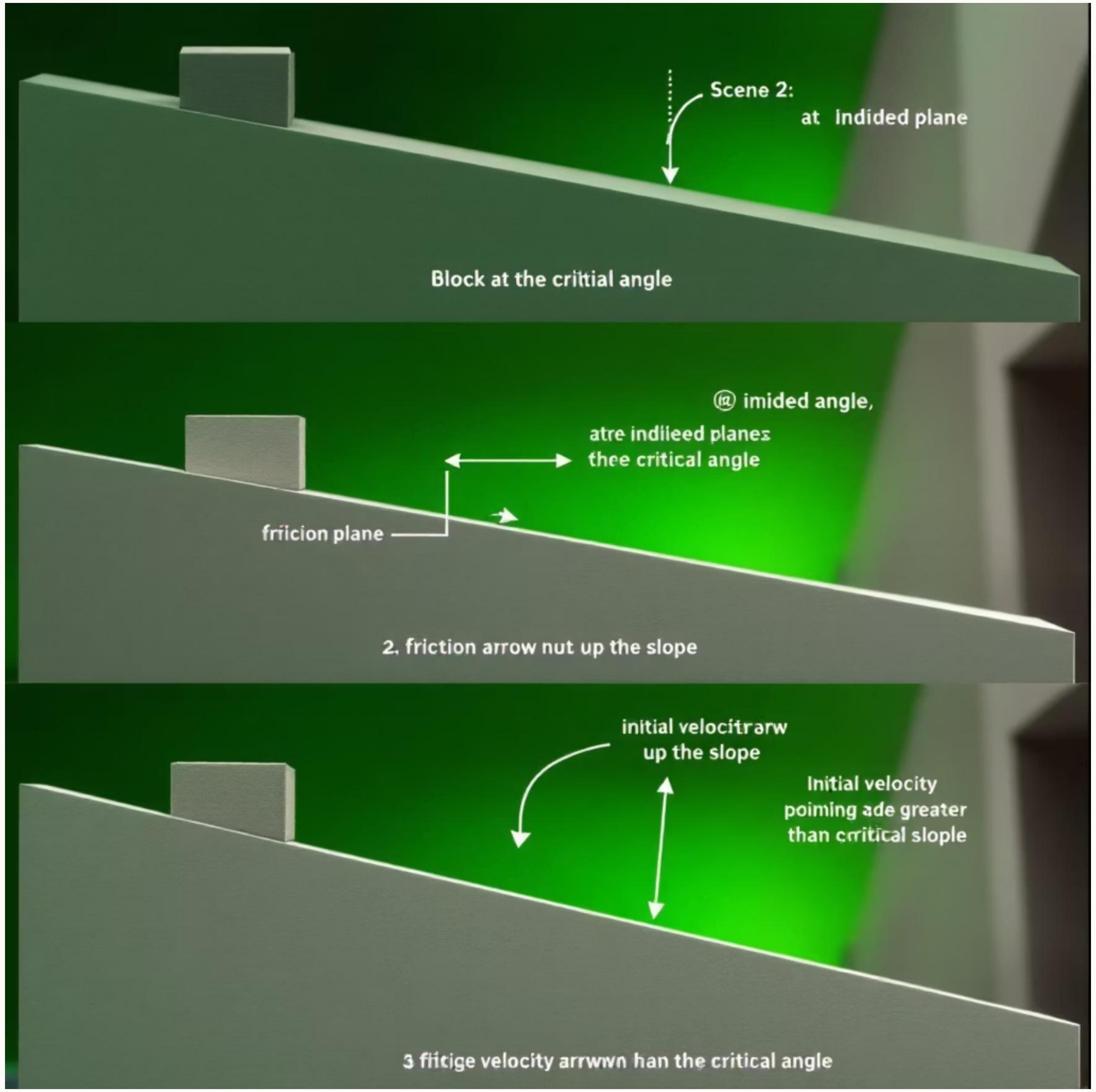
Approach:

The constraint here is that the acceleration of the movable pulley is half of the acceleration of mass C. Draw separate FBDs for A, B, and C. Write F_net = ma for each, and then use the kinematic constraints to relate their accelerations.

Advanced Challenge #4: Friction & Critical Force

A block of mass m is placed on a rough inclined plane with coefficients of friction $\mu s = 0.8$ and $\mu k = 0.5$. The inclination angle θ is gradually increased from 0°.

- (a) At what angle θc does the block just start to slip?
- (b) What is the magnitude and direction of the frictional force when $\theta = 30°$?
- (c) If the block is projected up the incline at $\theta = 30°$ with an initial speed v_0, what is the magnitude and direction of its acceleration?



⚠ Crucial Points:

This problem tests a deep understanding of static and kinetic friction. For part (b), remember to check if tan(30°) is greater or less than μs. For part (c), remember the direction of friction will oppose the relative motion, which is initially up the plane, so friction acts down the plane.

Thank You

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