

Motion in a Straight Line · Concept 2

Acceleration

The calculus and geometry of
changing velocity.

Defining Acceleration

Acceleration measures the rate of change of velocity with time. It can be measured over a finite interval or at an exact, infinitesimally small moment.

Average Acceleration

Measures average change over a **finite time interval**. It represents the slope of the secant line connecting (v_1, t_1) and (v_2, t_2) on a velocity-time graph.

$$a = \frac{\Delta v}{\Delta t}$$

$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

Instantaneous Acceleration

Measures velocity change as the time interval approaches zero ($\Delta t \rightarrow 0$). It represents the exact slope of the tangent line to the v - t curve at any given instant.

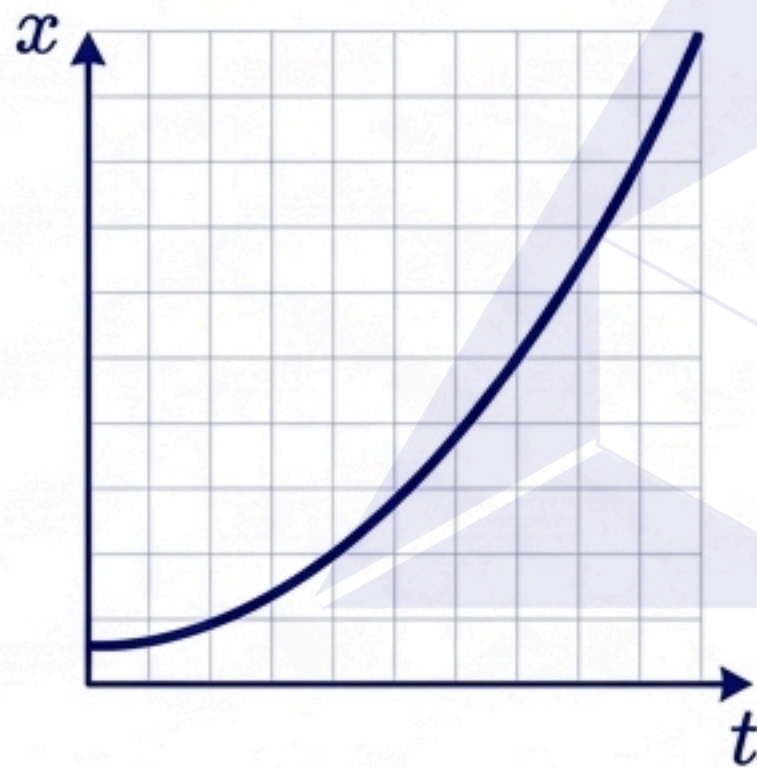
$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t}$$

$$a = \frac{dv}{dt}$$

How Acceleration Shapes Position

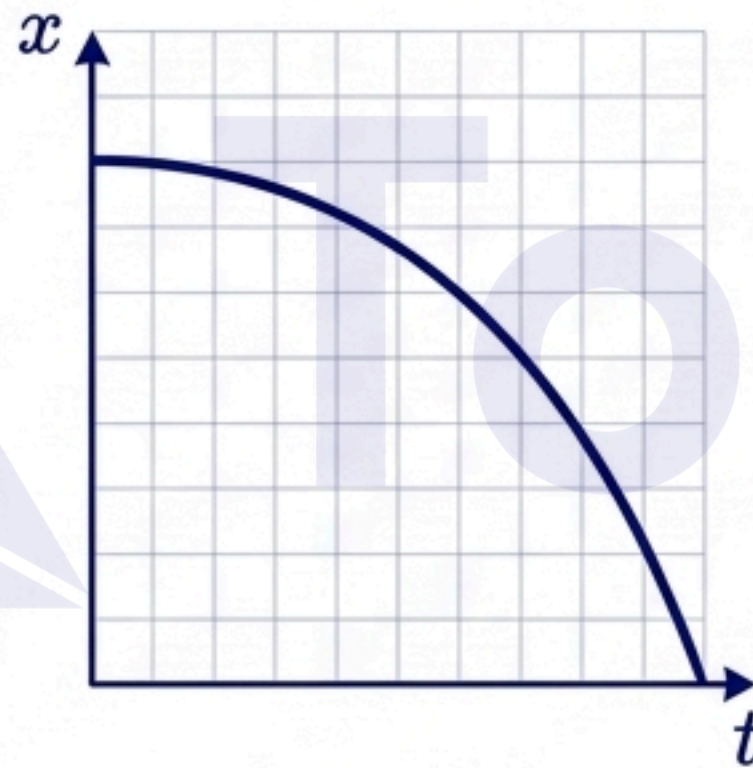
Because acceleration changes velocity, an object covers different distances in equal time intervals. This causes the position-time ($x-t$) graph to warp into a curve.

Positive Acceleration



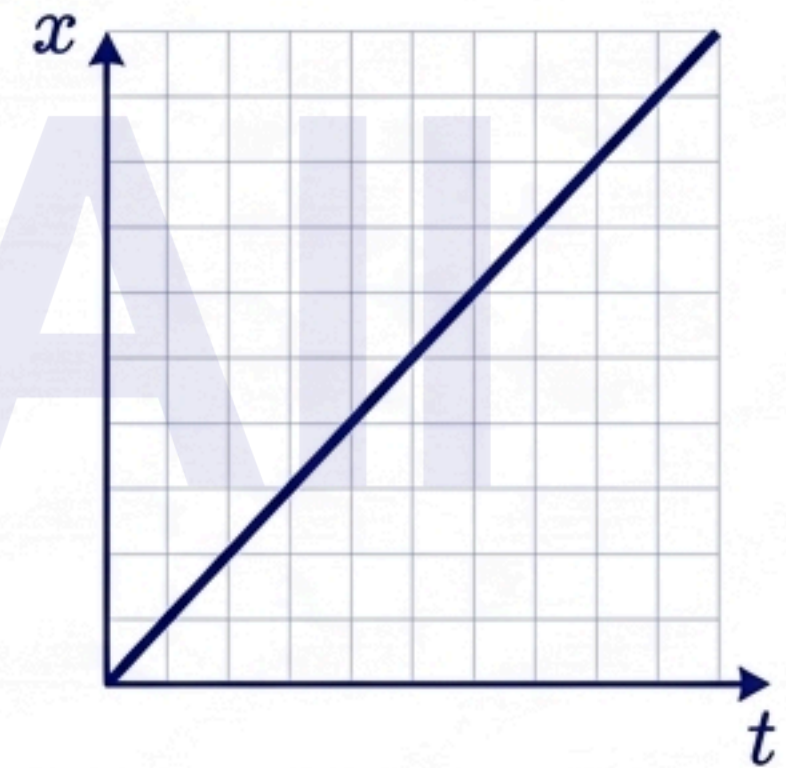
Velocity is increasing. The slope of the $x-t$ graph gets progressively steeper in the positive direction.

Negative Acceleration



Velocity is decreasing or becoming more negative. The slope flattens out or turns downward.

Zero Acceleration



Constant velocity. The object covers equal distances in equal times, yielding a constant $x-t$ slope.



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$$E=mc^2$$



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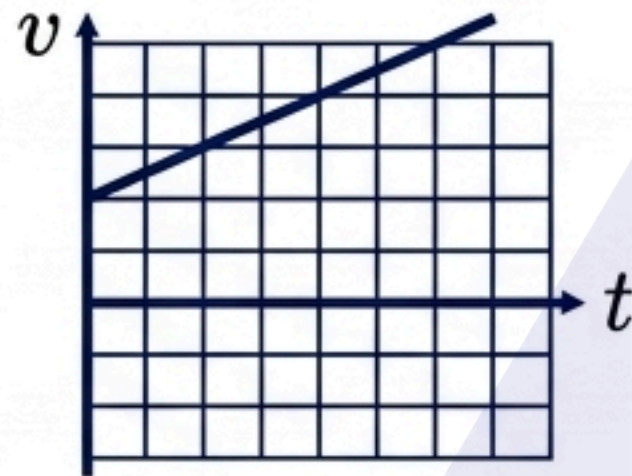
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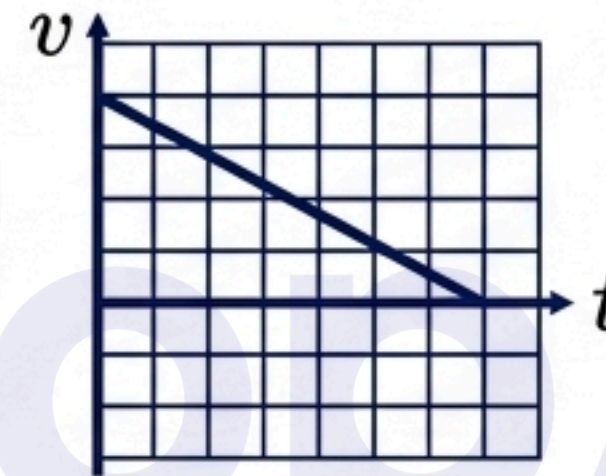


Constant Acceleration on a v-t Graph

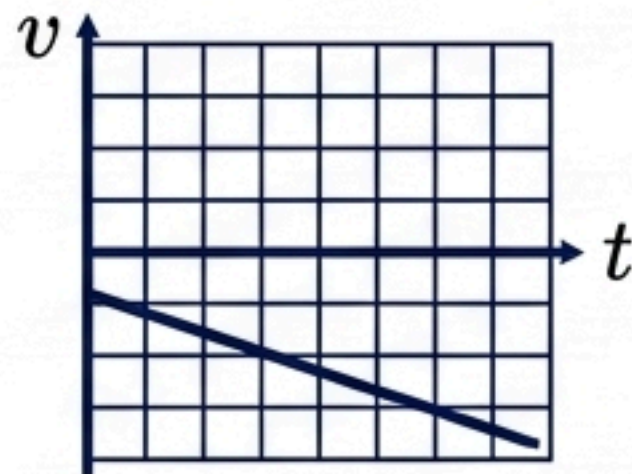
For constant acceleration, velocity changes at a steady rate. The v-t graph is always a straight line where the slope strictly equals the acceleration.



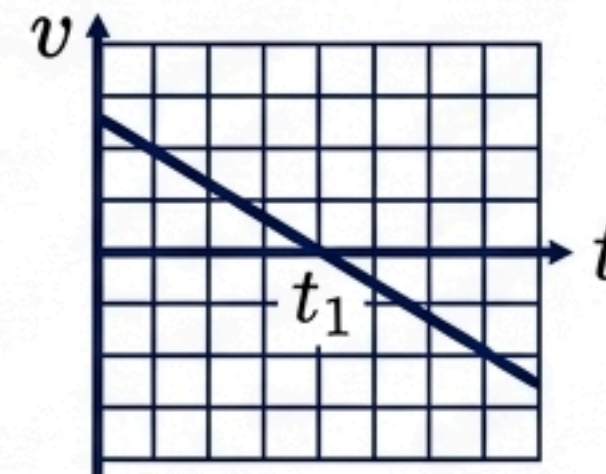
Motion in positive direction, positive acceleration
($v > 0, a > 0$)



Motion in positive direction, negative acceleration
($v > 0, a < 0$)



Motion in negative direction, negative acceleration
($v < 0, a < 0$)



Direction Reversal

Between 0 and t_1 , object moves in positive x-direction. At t_1 , $v = 0$. After t_1 , it moves in the opposite (negative) direction.

Reverse Engineering Displacement

An intrinsic mathematical feature of any v - t graph: the geometric area under the curve represents the total displacement over that time interval.

Constant Velocity

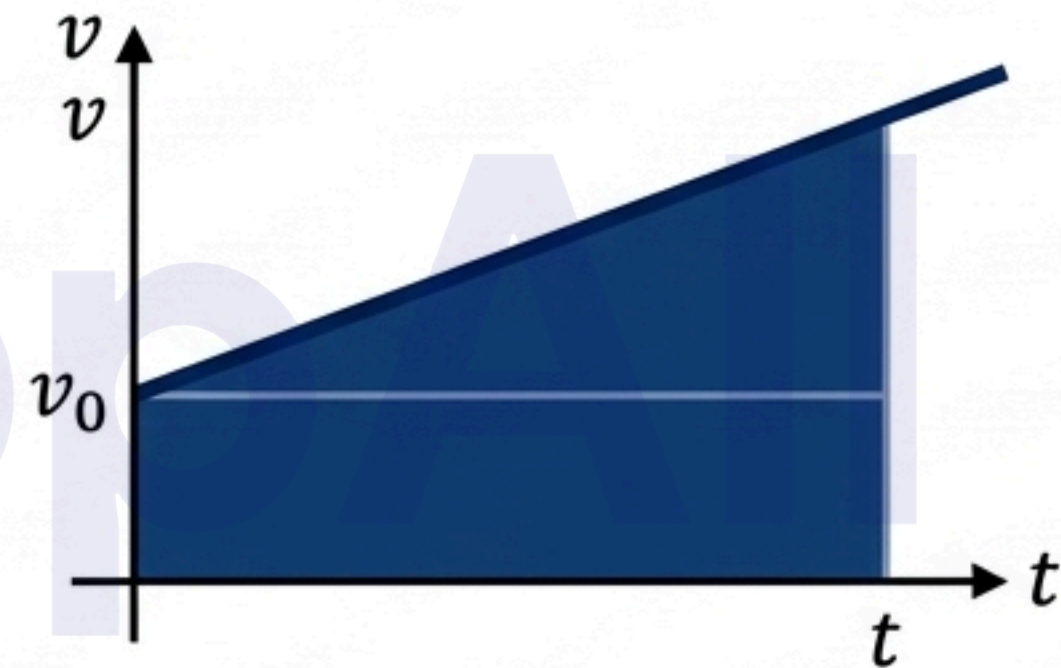


Area of Rectangle

$$\text{Area} = u \times T = uT$$

Velocity u multiplied by Time T perfectly yields displacement.

Constant Acceleration



Area = (Area of Triangle) + (Area of Rectangle)

$$\text{Area} = \frac{1}{2}(v - v_0)t + v_0t$$

This geometric area directly derives the kinematic equation: $x = v_0t + \frac{1}{2}at^2$.

Common Misconceptions About Acceleration

Trap 1: "Zero Velocity means Zero Acceleration"

The Reality: Zero velocity at an instant does not imply zero acceleration.

Example: A ball thrown straight up has $v = 0$ at its exact peak, but its acceleration continues to be $-g$ (gravity) downward. If acceleration were zero, it would float at the peak forever!

Trap 2: "Negative Acceleration means Speeding Down"

The Reality: The sign (+ or $-$) of acceleration depends entirely on your chosen positive coordinate axis, not on whether speed is increasing or decreasing.

Example: If you drop a ball and choose 'up' as positive, its acceleration is negative. But its speed is increasing as it falls.

Check Your Understanding

An object is moving with a negative velocity and a negative acceleration. What is happening to the speed of the object?

Option A: The speed is decreasing, and the object is returning to the origin.

Option B: The speed is increasing in the negative direction.

Option C: The speed is constant because both signs are negative.

Option D: The object is momentarily at rest.

Explanation

Correct Answer: B

If a particle is speeding up, acceleration is in the same direction as velocity. Since both $v < 0$ and $a < 0$, they act in the same direction, meaning the magnitude of velocity (speed) is actively increasing.

✓ Key Takeaways

- ✓ • **Acceleration is a slope:** The instantaneous acceleration $a = dv/dt$ is the exact slope of the tangent to the $v-t$ curve at any given instant.
- ✓ • **Curves reveal acceleration:** On a position-time ($x-t$) graph, positive acceleration curves upward, negative curves downward, and zero acceleration is a straight line.
- ✓ • **Area equals displacement:** The geometric area under any velocity-time ($v-t$) curve over a given time interval mathematically equals the object's displacement.
- ✓ • **Signs are relative:** The sign of acceleration depends solely on your chosen coordinate axis choice, not on whether the object is speeding up or slowing down.



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