PHYS11 CH:3 The Rate of Change

Understanding Acceleration

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December 2025

Outline

The Mystery of Motion

What if you could feel

the rate at which change happens?

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the rate at which change happens?

From the airplane landing to the dragster launching...

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What if you could feel
the rate at which change happens?

From the airplane landing to the dragster launching...

You experience acceleration every day.

Landing in St. Maarten

Figure: A plane slows down as it comes in for landing

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Figure: A plane slows down as it comes in for landing

The Paradox

Civilian: "Acceleration means speeding up."
Physicist: "Acceleration is ANY change in velocity - speeding up, slowing down, or turning."

Learning Objectives

By the end of this section, you will be able to:

- **3.1:** Explain acceleration and determine direction and magnitude in one dimension

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By the end of this section, you will be able to:

- **3.1:** Explain acceleration and determine direction and magnitude in one dimension
- **3.1:** Analyze motion using kinematic equations and graphic representations

Nature's Rule for Acceleration

$$\boxed{\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}}$$

Acceleration equals change in velocity divided by change in time.

3.1 The Source Code of Change

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SI Units: meters per second per second (m/s^2)

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The Mental Model

If velocity is how fast you're going, acceleration is how fast your "how fast" is changing.

Positive Acceleration

- Velocity and acceleration in same direction
- Speeding up to the right
- Slowing down to the left

3.1 Understanding the Sign

Positive Acceleration

- Velocity and acceleration in same direction
- Speeding up to the right
- Slowing down to the left

Negative Acceleration

- Velocity and acceleration in opposite directions
- Slowing down to the right
- Speeding up to the left

3.1 Understanding the Sign

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Negative Acceleration

- Velocity and acceleration in opposite directions
- Slowing down to the right
- Speeding up to the left

Key Insight

The sign tells you the DIRECTION, not whether you're speeding up or slowing down!

3.1 Speeding Up and Slowing Down

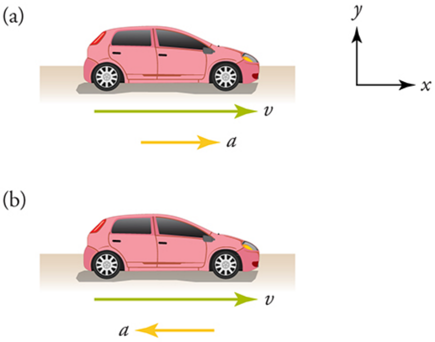

Figure: (a) Car speeding up, (b) Car slowing down

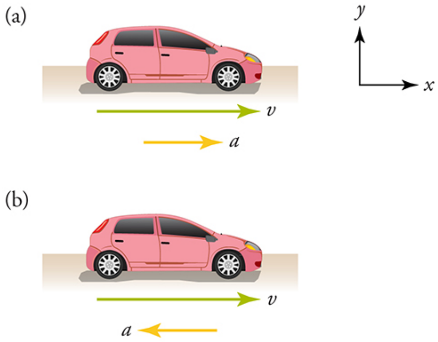

Figure: (a) Car speeding up, (b) Car slowing down

The Rule:

- Same direction = speeding up
- Opposite direction = slowing down

3.1 Acceleration is a Vector

Vector quantities have both magnitude AND direction:

- Displacement

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Critical insight: An object traveling at constant speed can still accelerate if it changes direction!

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Real-World: Turning

When you turn the steering wheel in a moving car, the car accelerates even if the speedometer doesn't change.

Attempt: Subway Train Accelerating

The Challenge (3 min, silent)

A subway train accelerates from rest to 30.0 km/h in 20.0 s.

Given:

- Initial velocity: $v_0 = 0$ (starts from rest)
- Final velocity: $v_f = 30.0$ km/h
- Time interval: $\Delta t = 20.0$ s

Find: Average acceleration in m/s^2

Can you decode this motion? Work silently. Remember to convert units!

Compare: Unit Conversion Strategy

Turn and talk (2 min):

1. What equation did you use for acceleration?
2. How did you convert km/h to m/s?
3. What multiplication factors did you use?

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1. What equation did you use for acceleration?
2. How did you convert km/h to m/s?
3. What multiplication factors did you use?

Name wheel: One pair share your approach (not your answer).

Reveal: The Acceleration Calculation

Self-correct in a different color:

Step 1: Convert 30.0 km/h to m/s

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$$30.0 \frac{\text{km}}{\text{h}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 8.333 \text{ m/s}$$

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Step 2: Calculate $\Delta v = v_f - v_0 = 8.333 - 0 = 8.333$ m/s

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Step 2: Calculate $\Delta v = v_f - v_0 = 8.333 - 0 = 8.333$ m/s
Step 3: Apply the equation

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{8.333\ \text{m/s}}{20.0\ \text{s}} = \boxed{+0.417\ \text{m/s}^2}$$

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Check: Positive sign means acceleration to the right. Reasonable for train speeding up!

Attempt: Subway Train Slowing Down

The Challenge (3 min, silent)

Now the train slows to a stop from 30.0 km/h in 8.00 s.

Given:

- Initial velocity: $v_0 = 30.0\ \text{km/h} = 8.333\ \text{m/s}$
- Final velocity: $v_f = 0$ (comes to rest)
- Time interval: $\Delta t = 8.00\ \text{s}$

Find: Average acceleration in m/s^2

Will the sign be positive or negative? Why?

Compare: Sign of Acceleration

Turn and talk (2 min):

1. What did you get for Δv?
2. Is it positive or negative?
3. What does the sign of acceleration tell you?

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Name wheel: Share your reasoning about the sign.

Reveal: Deceleration Calculation

Self-correct in a different color:

Step 1: Calculate $\Delta v = v_f - v_0 = 0 - 8.333 = -8.333$ m/s

Reveal: Deceleration Calculation

Self-correct in a different color:

Step 1: Calculate $\Delta v = v_f - v_0 = 0 - 8.333 = -8.333$ m/s
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$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{-8.333 \text{ m/s}}{8.00 \text{ s}} = \boxed{-1.04 \text{ m/s}^2}$$

Reveal: Deceleration Calculation

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Check: Negative sign means acceleration to the left (opposite to velocity). Train is slowing down!

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Physics vs Civilian Language

Civilian: "The train is decelerating."
Physicist: "The train has negative acceleration."

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- **3.2:** Explain kinematic equations related to acceleration and illustrate with graphs

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- **3.2:** Explain kinematic equations related to acceleration and illustrate with graphs
- **3.2:** Apply kinematic equations and graphs to problems involving acceleration

For constant acceleration only:

$$d = d_0 + \bar{v}\,t \tag{1}$$

$$\bar{v} = \frac{v_0 + v_f}{2} \tag{2}$$

$$v = v_0 + at \tag{3}$$

$$d = d_0 + v_0\,t + \frac{1}{2}at^2 \tag{4}$$

$$v^2 = {v_0}^2 + 2a(d - d_0) \tag{5}$$

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The Mental Model

These five equations are the grammar of motion. Learn which one to use when.

3.2 Displacement vs Time

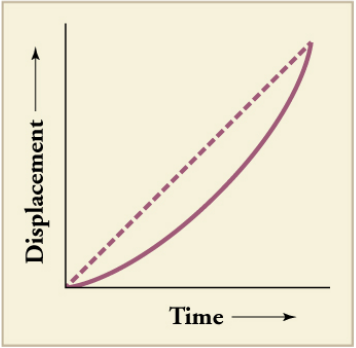
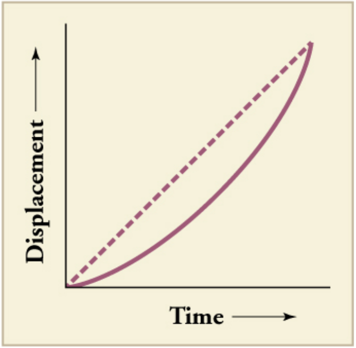


Figure: Slope of displacement vs time gives velocity



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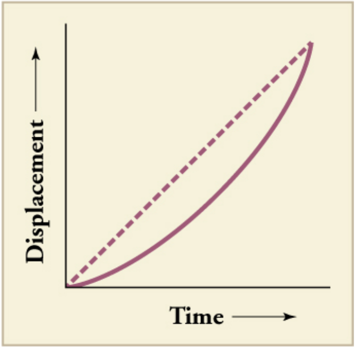
Key insight:

$$\bar{v} = \frac{d}{t} \quad \text{(when starting from origin)}$$



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The slope IS the velocity!

3.2 Velocity vs Time

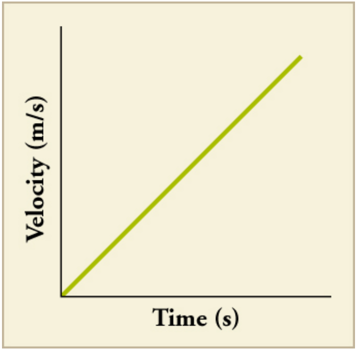
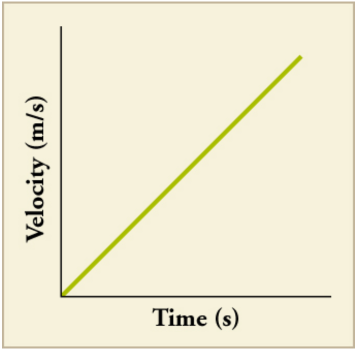


Figure: Slope of velocity vs time gives acceleration



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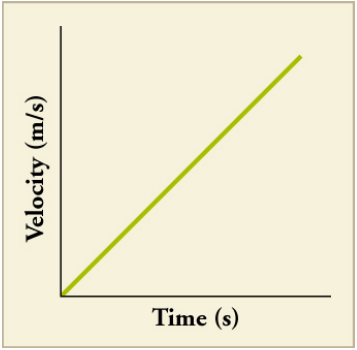

Figure: Slope of velocity vs time gives acceleration

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The slope IS the acceleration!

3.2 Choosing the Right Equation

Strategy:

1. List the knowns

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Example Decision Tree

- Time not given? Use equation 5: $v^2 = {v_0}^2 + 2a(d - d_0)$
- Displacement not needed? Use equation 3: $v = v_0 + at$
- From rest ($v_0 = 0$)? Equations simplify!

Attempt: Dragster Problem

The Challenge (3 min, silent)

A dragster accelerates from rest at 26.0 m/s^2 for a quarter mile (402 m).

Given:

- $v_0 = 0$ (starts from rest)
- $a = 26.0$ m/s^2
- $d - d_0 = 402$ m

Find: Final velocity v_f

Which kinematic equation should you use? Why?

Compare: Equation Selection

Turn and talk (2 min):

1. Which equation did you choose?
2. Why is that equation appropriate?
3. What variables does it NOT include?

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Name wheel: One pair explain their equation choice.

Reveal: Dragster Speed

Self-correct in a different color:

Step 1: Choose equation 5 (no time): $v^2 = {v_0}^2 + 2a(d - d_0)$

Reveal: Dragster Speed

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Step 1: Choose equation 5 (no time): $v^2 = {v_0}^2 + 2a(d - d_0)$
Step 2: Since $v_0 = 0$: $v^2 = 2a(d - d_0)$
Step 3: Substitute values

$$v^2 = 2(26.0)(402) = 2.09 \times 10^4 \ \mathrm{m}^2/\mathrm{s}^2$$

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Step 4: Take square root

$$v = \sqrt{2.09 \times 10^4} = \boxed{145 \text{ m/s}}$$

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Check: About 324 mph - reasonable for dragster!

Nature's Constant

$$\boxed{g = 9.80\ \mathrm{m/s^2}}$$

Near Earth's surface, all objects fall with this acceleration (ignoring air resistance).

3.2 Acceleration Due to Gravity

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Convention: When using g in equations, give it a negative sign because gravity points downward.

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Convention: When using g in equations, give it a negative sign because gravity points downward.

The Mental Model

Every second of free fall, velocity increases by 9.80 m/s downward.

Attempt: Rock Thrown Upward

The Challenge (3 min, silent)

A rock is thrown straight up with initial velocity $v_0 = 13.0$ m/s.

Given:

- $v_0 = 13.0$ m/s (upward)
- $a = -9.80$ m/s^2 (gravity)
- $t = 1.00$ s

Find:

- Position y at 1.00 s
- Velocity v at 1.00 s

Choose your equations wisely!

Compare: Gravity Problems

Turn and talk (2 min):

1. Which equations did you use?
2. How did you handle the negative sign for gravity?
3. Is the rock still going up or coming down?

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1. Which equations did you use?
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Name wheel: Share your approach.

Reveal: Rock Position and Velocity

Self-correct in a different color:
Position: $y = y_0 + v_0 t + \frac{1}{2} a t^2$

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Self-correct in a different color:
Position: $y = y_0 + v_0 t + \frac{1}{2} a t^2$

$$y = 0 + (13.0)(1.00) + \frac{1}{2}(-9.80)(1.00)^2 = \boxed{8.10 \text{ m}}$$

Reveal: Rock Position and Velocity

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Velocity: $v = v_0 + at$

$$v = 13.0 + (-9.80)(1.00) = \boxed{3.20\text{ m/s}}$$

Check: Positive position (above starting point) and positive velocity (still going up). Makes sense!

What You Now Know

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1. Acceleration = rate of change of velocity (direction matters!)
2. $\bar{a} = \Delta v / \Delta t$ - the definition of acceleration
3. Five kinematic equations predict motion
4. Graphs reveal acceleration as slopes
5. $g = 9.80 \text{ m/s}^2$ - Earth's gravitational acceleration
6. Choose equations based on knowns and unknowns

Key Equations

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0} \tag{6}$$

$$d = d_0 + \bar{v}t \tag{7}$$

$$\bar{v} = \frac{v_0 + v_f}{2} \tag{8}$$

$$v = v_0 + at \tag{9}$$

$$d = d_0 + v_0 t + \frac{1}{2}at^2 \tag{10}$$

$$v^2 = {v_0}^2 + 2a(d - d_0) \tag{11}$$

$$g = 9.80 \text{ m/s}^2 \tag{12}$$

Homework

Complete the assigned problems

posted on the LMS

Temporary page!

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was some unprocessed data that should have been added to the
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