PHYS11 CH:3 The Rate of Change

Understanding Acceleration

Mr. Gullo

December 2025

Outline

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

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

From the airplane landing to the dragster launching...

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

Landing in St. Maarten

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

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
- **3.1:** Analyze motion using kinematic equations and graphic representations

3.1 The Source Code of Change

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.

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.

SI Units: meters per second per second ($\mathrm{m/s^2}$)

3.1 The Source Code of Change

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.

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

The Mental Model

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

3.1 Understanding the Sign

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

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

Key Insight

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

3.1 Speeding Up and Slowing Down

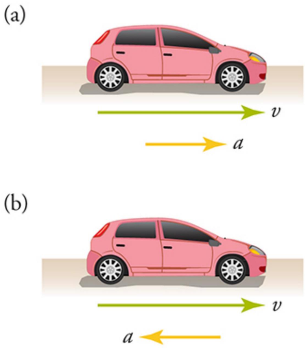

Figure: (a) Car speeding up, (b) Car slowing down

3.1 Speeding Up and Slowing Down

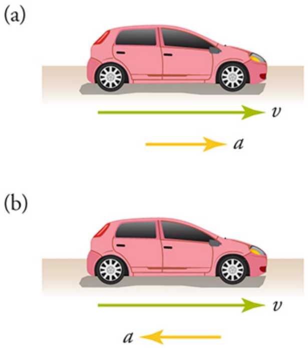

Figure: (a) Car speeding up, (b) Car slowing down

The Rule:

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

3.1 Acceleration is a Vector

Vector quantities have both magnitude AND direction:

- Displacement

3.1 Acceleration is a Vector

Vector quantities have both magnitude AND direction:

- Displacement
- Velocity

3.1 Acceleration is a Vector

Vector quantities have both magnitude AND direction:

- Displacement
- Velocity
- Acceleration

3.1 Acceleration is a Vector

Vector quantities have both magnitude AND direction:

- Displacement
- Velocity
- Acceleration

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

3.1 Acceleration is a Vector

Vector quantities have both magnitude AND direction:

- Displacement
- Velocity
- Acceleration

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

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 $\mathrm{m/s^2}$

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?

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?

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

Reveal: The Acceleration Calculation

Self-correct in a different color:

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

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

Reveal: The Acceleration Calculation

Self-correct in a different color:

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

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

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

Reveal: The Acceleration Calculation

Self-correct in a different color:

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

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

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

Step 3: Apply the equation

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

Self-correct in a different color:

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

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

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

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

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?

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?

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
Step 2: Apply the equation

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{-8.333 \text{ m/s}}{8.00 \text{ s}} = \boxed{-1.04 \text{ m/s}^2}$$

Reveal: Deceleration Calculation

Self-correct in a different color:

Step 1: Calculate $\Delta v = v_f - v_0 = 0 - 8.333 = -8.333$ m/s
Step 2: Apply the equation

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{-8.333 \text{ m/s}}{8.00 \text{ s}} = \boxed{-1.04 \text{ m/s}^2}$$

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

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
Step 2: Apply the equation

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{-8.333 \text{ m/s}}{8.00 \text{ s}} = \boxed{-1.04 \text{ m/s}^2}$$

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

Physics vs Civilian Language

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

Learning Objectives

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

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

Learning Objectives

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

- **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:

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

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

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

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

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

For constant acceleration only:

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

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

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

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

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

The Mental Model

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

3.2 Displacement vs Time

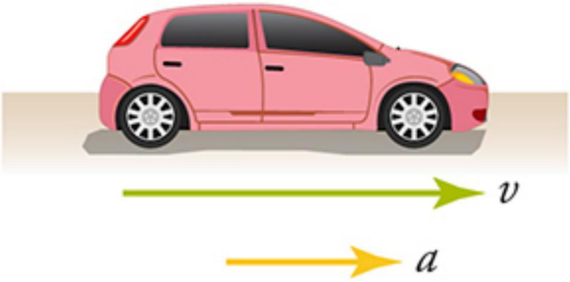

Figure: Slope of displacement vs time gives velocity

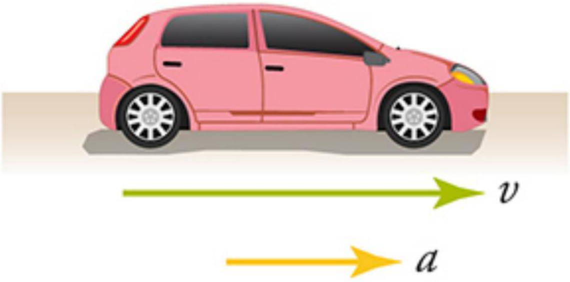

Figure: Slope of displacement vs time gives velocity

Key insight:

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

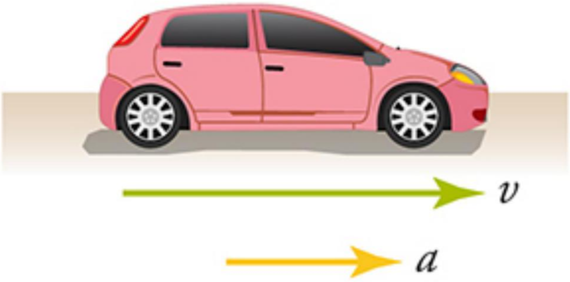

Figure: Slope of displacement vs time gives velocity

Key insight:

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

The slope IS the velocity!

3.2 Velocity vs Time

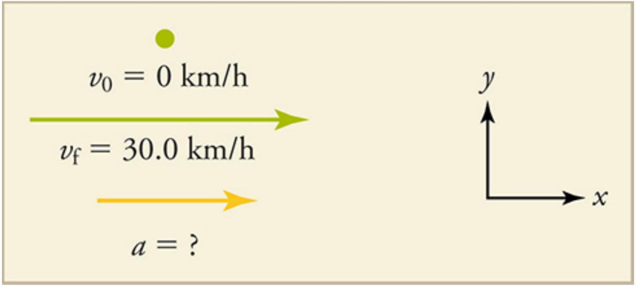

Figure: Slope of velocity vs time gives acceleration

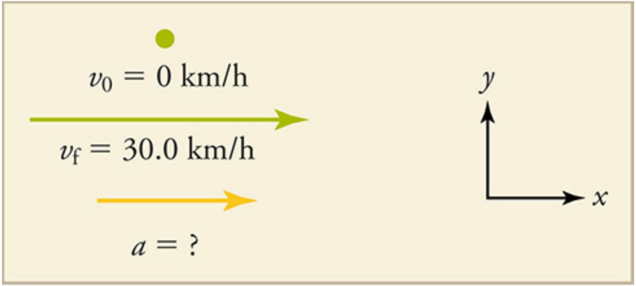

Figure: Slope of velocity vs time gives acceleration

Key insight:

$$a = \frac{v}{t} \quad \text{(when starting from rest)}$$

3.2 Velocity vs Time

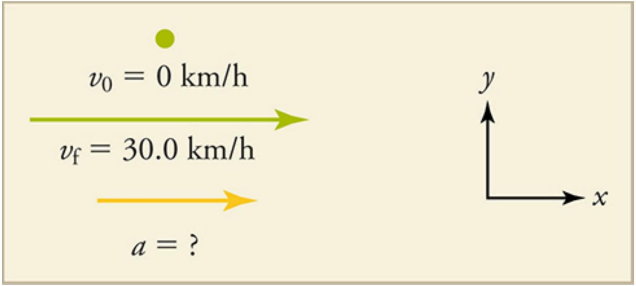

Figure: Slope of velocity vs time gives acceleration

Key insight:

$$a = \frac{v}{t} \quad \text{(when starting from rest)}$$

The slope IS the acceleration!

Strategy:

1. List the knowns

3.2 Choosing the Right Equation

Strategy:

1. List the knowns
2. Identify the unknown

3.2 Choosing the Right Equation

Strategy:

1. List the knowns
2. Identify the unknown
3. Pick equation with unknown and all knowns

3.2 Choosing the Right Equation

Strategy:

1. List the knowns
2. Identify the unknown
3. Pick equation with unknown and all knowns

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?

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?

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

Self-correct in a different color:

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

Reveal: Dragster Speed

Self-correct in a different color:

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

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

Reveal: Dragster Speed

Self-correct in a different color:

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

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

Step 4: Take square root

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

Reveal: Dragster Speed

Self-correct in a different color:

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

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

Step 4: Take square root

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

Check: About 324 mph - reasonable for dragster!

3.2 Acceleration Due to Gravity

Nature's Constant

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

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

3.2 Acceleration Due to Gravity

Nature's Constant

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

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

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

Nature's Constant

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

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

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?

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?

Name wheel: Share your approach.

Reveal: Rock Position and Velocity

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

Reveal: Rock Position and Velocity

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

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

Reveal: Rock Position and Velocity

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

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

Velocity: $v = v_0 + at$

Reveal: Rock Position and Velocity

Self-correct in a different color:

Position: $y = y_0 + v_0 t + \frac{1}{2}at^2$

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

Velocity: $v = v_0 + at$

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

Reveal: Rock Position and Velocity

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

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

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

The Revelations

1. Acceleration = rate of change of velocity (direction matters!)

What You Now Know

The Revelations

1. Acceleration = rate of change of velocity (direction matters!)
2. $\bar{a} = \Delta v / \Delta t$ - the definition of acceleration

What You Now Know

The Revelations

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

What You Now Know

The Revelations

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

What You Now Know

The Revelations

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. $g = 9.80$ m/s^2 - Earth's gravitational acceleration

What You Now Know

The Revelations

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