PHYS11 CH:2 How to Measure Motion

Distance, Displacement, Speed, and Velocity

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Outline

How do you know something is moving?

How do you know something is moving?

Everything is in motion. Your heart pumps blood. Atoms vibrate. Earth orbits the Sun.

How do you know something is moving?

Everything is in motion. Your heart pumps blood. Atoms vibrate. Earth orbits the Sun.

But motion is always relative to something.

What Is Kinematics?

The Study of Motion

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Real-World Examples

- Tennis ball flying across court
- Spacecraft orbiting Mars
- Your walk to class

Learning Objectives

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

- **2.1:** Describe motion in different reference frames

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- **2.1:** Define distance and displacement, and distinguish between the two

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

- **2.1:** Describe motion in different reference frames
- **2.1:** Define distance and displacement, and distinguish between the two
- **2.1:** Solve problems involving distance and displacement

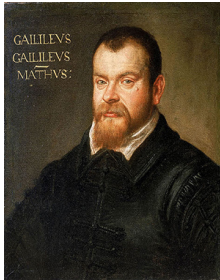Figure: Are clouds a useful reference frame for airplane passengers?

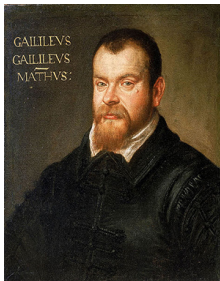Figure: Are clouds a useful reference frame for airplane passengers?

Reference frame: The coordinate system from which positions are described.
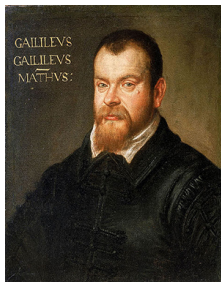
Galileo Galilei (1564-1642)

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Thought experiment: Person in windowless ship on calm sea.

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Thought experiment: Person in windowless ship on calm sea.
Can they tell if the ship is moving?

2.1 Galileo's Conclusion

Universal Truth

Only by comparing to each other can observers describe relative motion.

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Universal Truth

Only by comparing to each other can observers describe relative motion.

Person on ship: "Shore is moving past me."
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The Paradox

Both are correct! Description depends on the reference frame.

Distance

Total length of the path traveled. (Scalar)

2.1 Two Ways to Measure Motion

Distance

Total length of the path traveled. (Scalar)

Displacement

Straight-line change in position from start to finish. (Vector)

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Displacement

Straight-line change in position from start to finish. (Vector)

Key Difference

Civilian: "I drove 100 km today."
Physicist: "But your displacement was 0 - you ended where you started."
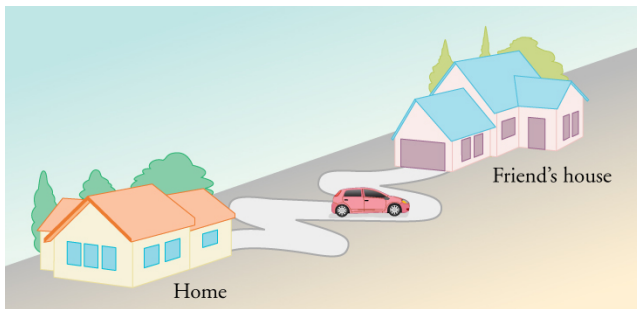
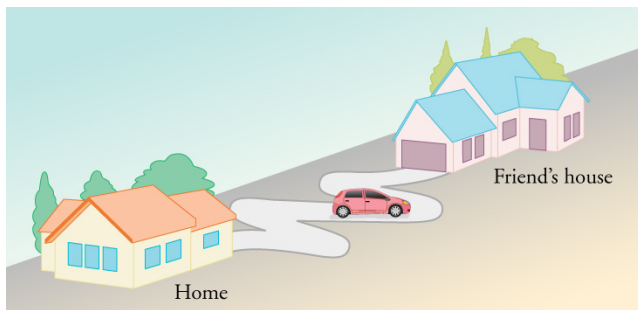Figure: Short line is displacement. Curved path is distance.

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Distance $\geq$ Displacement (always!)

2.1 The Round Trip

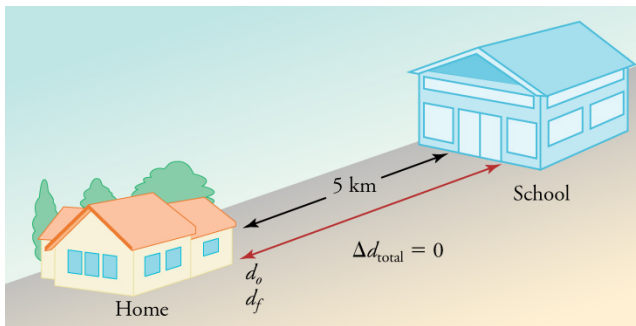
Figure: Drive to school (5 km) and back home (5 km)
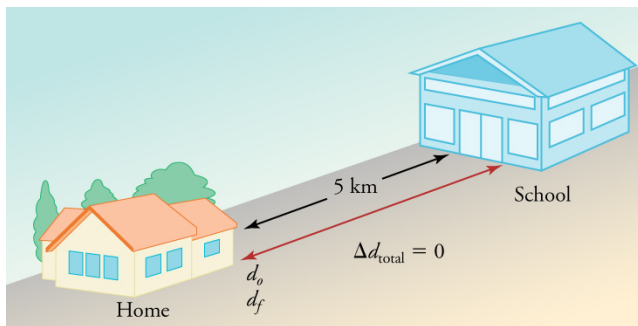
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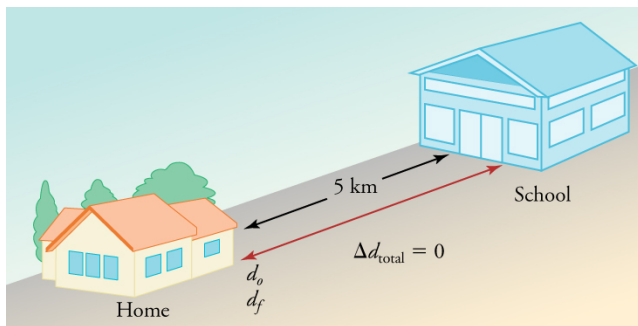
Distance: 10 km

Figure: Drive to school (5 km) and back home (5 km)

Distance: 10 km
Displacement: 0 km (start and end at same position)

Scalar

Magnitude only

Scalar

Magnitude only

Examples:

- Distance
- Speed
- Time
- Temperature
- Mass

2.1 Scalars vs. Vectors

Scalar	Vector
Magnitude only	Magnitude AND direction

Examples:

- Distance
- Speed
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Scalar
Magnitude only

Vector
Magnitude AND direction

Examples:

- Distance
- Speed
- Time
- Temperature
- Mass

Examples:

- Displacement
- Velocity
- Force
- Acceleration

2.1 Displacement Equation

Calculating Displacement

$$\Delta \mathbf{d} = \mathbf{d}_f - \mathbf{d}_0$$

Change in position equals final position minus initial position.

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Symbols:

- Δ (delta) = change in
- $\mathbf{d}_0$ = initial position
- $\mathbf{d}_f$ = final position

2.1 Choosing Your Axis

You must define:

1. Origin (zero point)

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3. Negative direction (opposite)

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Smart Choices

Choose origin and direction to make calculations easiest.

- Often: starting position $= 0$
- Often: forward/right $=$ positive

The Challenge (3 min, silent)

A cyclist rides 3 km west and then turns around and rides 2 km east.

Find:

- (a) Displacement
- (b) Distance traveled
- (c) Magnitude of displacement

Hint: Choose your positive direction first. Work silently.

Turn and talk (2 min):

1. Which direction did you choose as positive?
2. What was your displacement value?
3. Did you get a negative displacement? What does that mean?
4. How is distance different from displacement?

Compare: The Cyclist

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1. Which direction did you choose as positive?
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Name wheel: One pair share your approach.

Self-correct in a different color:

Setup: Choose east = positive, west = negative

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(a) Displacement:
$$\Delta\mathbf{d} = \mathbf{d}_\mathrm{f} - \mathbf{d}_0 = -1 \text{ km}$$

(or 1 km west)

Reveal: The Cyclist Solution

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Setup: Choose east = positive, west = negative
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(b) Distance traveled:

$$\text{Distance} = 3 \text{ km} + 2 \text{ km} = 5 \text{ km}$$

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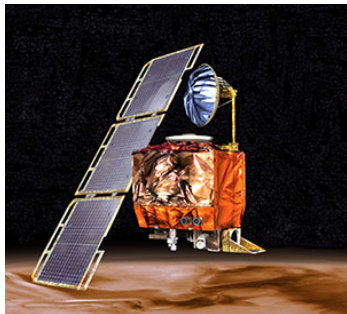
(c) Magnitude of displacement:

$$|\Delta \mathbf{d}| = 1 \text{ km}$$

Figure: Mars Climate Orbiter, 1998

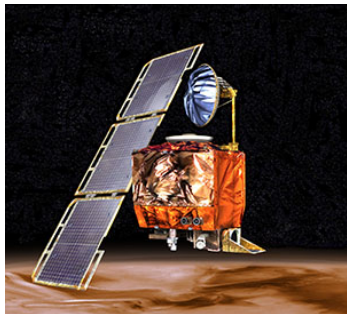Figure: Mars Climate Orbiter, 1998

Cost: $125 million
Mistake: Calculations in English units, not SI units
Result: Probe crashed into Mars atmosphere

Learning Objectives

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

- **2.2:** Calculate the average speed of an object

Learning Objectives

The Rate of Motion

Speed is the rate at which an object changes its location. (Scalar)

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SI unit: meters per second (m/s)
Other units: km/h, mph

2.2 What Is Speed?

The Rate of Motion

Speed is the rate at which an object changes its location. (Scalar)

SI unit: meters per second (m/s)
Other units: km/h, mph

The Mental Model

Speed is your odometer. It tells you how fast, but not where you're going.

2.2 Average Speed

Universal Law: Rate of Motion

$$v_{\text{avg}} = \frac{d}{t}$$

Average speed equals total distance divided by total time.

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Rearranged:

$$d = v_{\text{avg}} \times t$$

$$t = \frac{d}{v_{\text{avg}}}$$

Average speed**:** Total distance divided by total time

2.2 Average vs. Instantaneous Speed

Average speed: Total distance divided by total time

Example: Car travels 150 km in 3.2 hours

$$v_{\text{avg}} = \frac{150 \text{ km}}{3.2 \text{ h}} = 47 \text{ km/h}$$

2.2 Average vs. Instantaneous Speed

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Instantaneous speed: Speed at a specific instant

Real-World

Your car's speedometer shows instantaneous speed, not average.
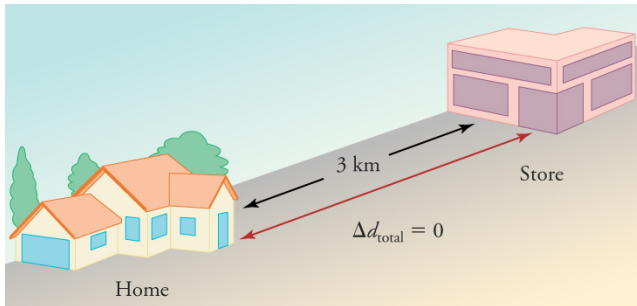
Figure: 30-minute round trip, 6 km total
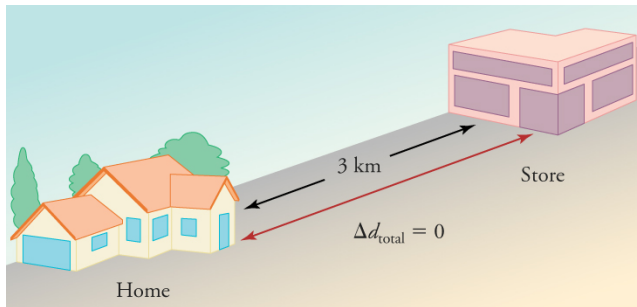
Figure: 30-minute round trip, 6 km total

Average speed: $\frac{6 \text{ km}}{0.5 \text{ h}} = 12$ km/h
Displacement: 0 km (round trip)

Attempt: The Marble

The Challenge (3 min, silent)

A marble rolls 5.2 m in 1.8 s.

Find: The marble's average speed

Work silently. Show your units.

Compare: The Marble

Turn and talk (2 min):

1. What formula did you use?
2. What did you divide?
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Reveal: The Marble Solution

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Given:

- Distance $= 5.2$ m
- Time $= 1.8$ s

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Substitute:

$$v_{\text{avg}} = \frac{5.2 \text{ m}}{1.8 \text{ s}} = 2.9 \text{ m/s}$$

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Check: About 3 m/s - speed of brisk walk. Reasonable!

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Speed Plus Direction

Velocity is the vector version of speed. It includes both magnitude (how fast) and direction (which way).

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Bold vs. italics:

- **v** = velocity (vector, includes direction)
- v = speed (scalar, magnitude only)

2.2 Average Velocity

Universal Law: Rate of Displacement

$$\mathbf{v}_{\text{avg}} = \frac{\Delta \mathbf{d}}{\Delta t} = \frac{\mathbf{d}_{\text{f}} - \mathbf{d}_0}{t_{\text{f}} - t_0}$$

Average velocity equals displacement divided by time interval.

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The Paradox

Round trip: Speed = 12 km/h, but velocity = 0 km/h!
(Displacement is zero)

Speed (Scalar)

- Uses distance
- Magnitude only
- Always positive
- Example: 50 km/h

2.2 Speed vs. Velocity

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Velocity (Vector)

- Uses displacement
- Magnitude + direction
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- Example: 50 km/h north

Civilian View vs. Reality

Civilian: "Speed and velocity are the same thing."
Physicist: "Speed is how fast. Velocity is how fast AND which way."

The Challenge (3 min, silent)

A student has a displacement of 304 m north in 180 s.

Find: The student's average velocity

Remember: velocity needs direction! Work silently.

Turn and talk (2 min):

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2. Did you include direction in your answer?
3. How many significant figures should the answer have?

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Name wheel: One pair share your complete answer with direction.

Self-correct in a different color:

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- Displacement $=$ 304 m north
- Time $=$ 180 s

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Given:

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- Time = 180 s

Equation:

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Equation:

$$\mathbf{v}_{\text{avg}} = \frac{\Delta \mathbf{d}}{\Delta t}$$

Substitute:

$$\mathbf{v}_{\text{avg}} = \frac{304 \text{ m}}{180 \text{ s}} = 1.7 \text{ m/s north}$$

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Note: 2 sig figs from time (180 s)

Average velocity: Over a time interval

2.2 Instantaneous Velocity

Average velocity: Over a time interval

Instantaneous velocity: At a specific instant in time

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Average velocity: Over a time interval

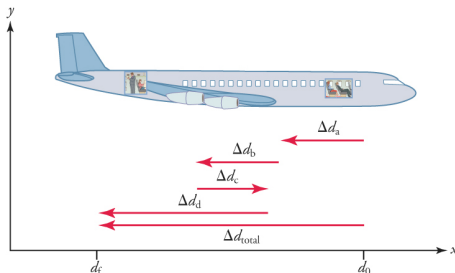**Instantaneous velocity:** At a specific instant in time

Figure: Airplane passenger velocity at different segments

Average velocity: Over a time interval

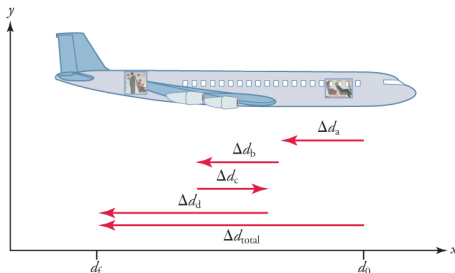**Instantaneous velocity:** At a specific instant in time

Figure: Airplane passenger velocity at different segments

If velocity is constant, instantaneous = average.

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The Revelations

1. Motion is relative - depends on reference frame
2. Distance (scalar) vs. displacement (vector)
3. Speed (scalar) vs. velocity (vector)
4. Displacement = final position - initial position
5. Average speed = distance / time
6. Average velocity = displacement / time

Key Equations

$$\Delta \mathbf{d} = \mathbf{d}_\mathrm{f} - \mathbf{d}_0 \tag{1}$$

$$v_\mathrm{avg} = \frac{d}{t} \tag{2}$$

$$\mathbf{v}_\mathrm{avg} = \frac{\Delta \mathbf{d}}{\Delta t} = \frac{\mathbf{d}_\mathrm{f} - \mathbf{d}_0}{t_\mathrm{f} - t_0} \tag{3}$$

Remember:

- Bold = vector (includes direction)
- Italic = scalar (magnitude only)

Complete the assigned problems

posted on the LMS

Temporary page!

LATEX was unable to guess the total number of pages correctly. A was some unprocessed data that should have been added to the this extra page has been added to receive it.

If you rerun the document (without altering it) this surplus page away, because LATEX now knows how many pages to expect for t document.