PHYS11 CH:2 How to Measure Motion

Distance, Displacement, Speed, and Velocity

Mr. Gullo

December 2025

Outline

The Mystery

How do you know something is moving?

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

The Mystery

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:** 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

2.1 The Reference Frame Problem

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

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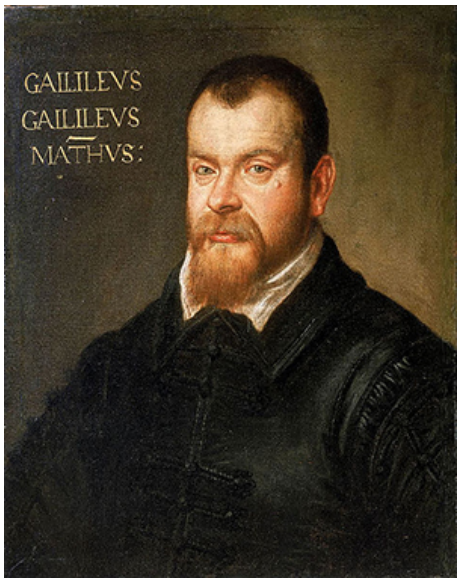
Reference frame: The coordinate system from which positions are described.

2.1 Galileo's Revelation



Galileo Galilei (1564-1642)

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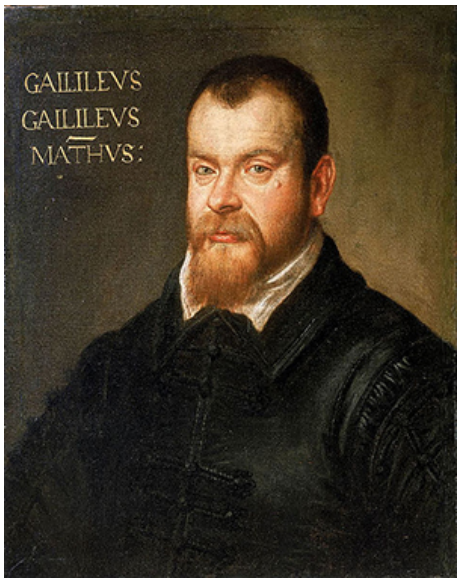

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Thought experiment: Person in windowless ship on calm sea.

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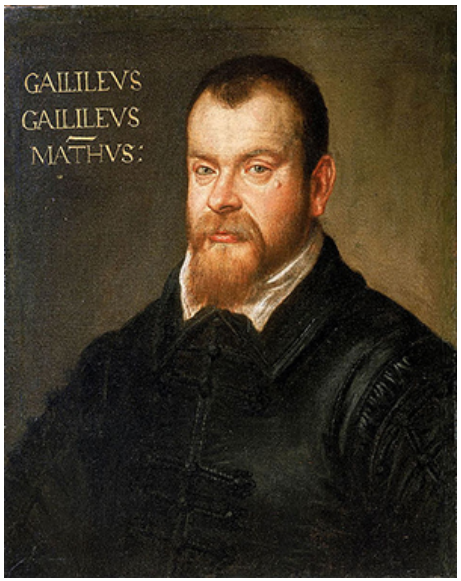

Galileo Galilei (1564-1642)

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.

2.1 Two Ways to Measure Motion

Distance

Total length of the path traveled. (Scalar)

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Displacement

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

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Key Difference

Civilian: "I drove 100 km today."
Physicist: "But your displacement was 0 - you ended where you started."

2.1 Visualizing Distance vs. Displacement

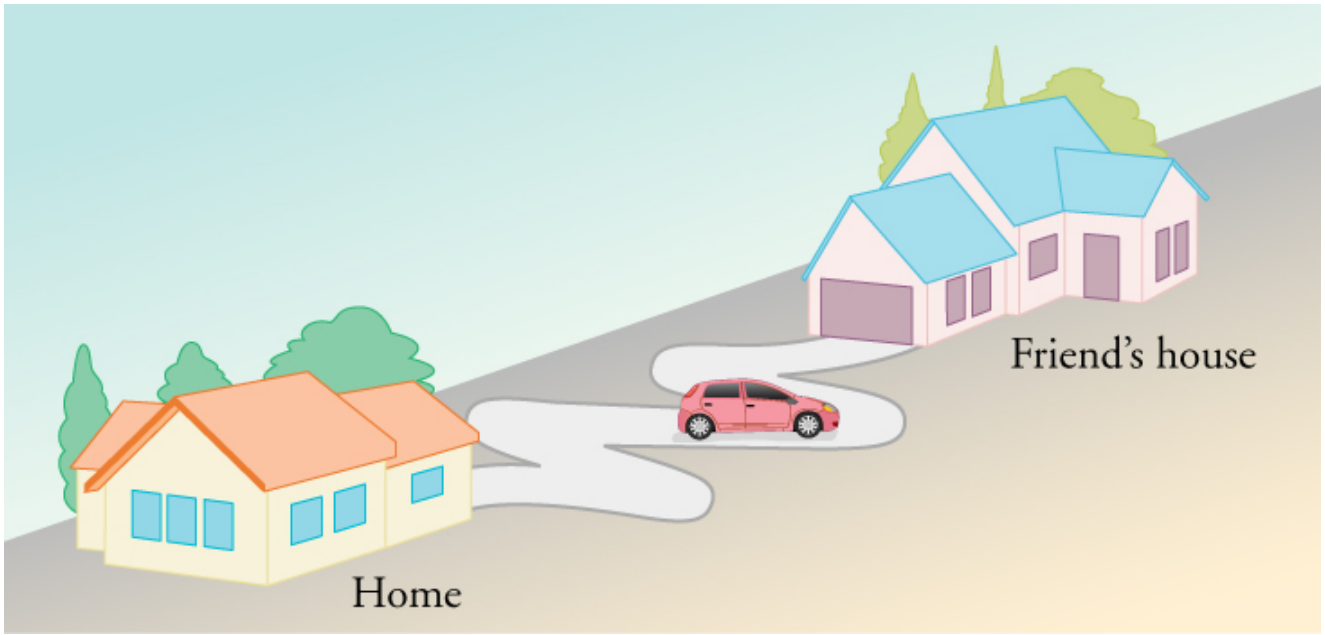

Figure: Short line is displacement. Curved path is distance.

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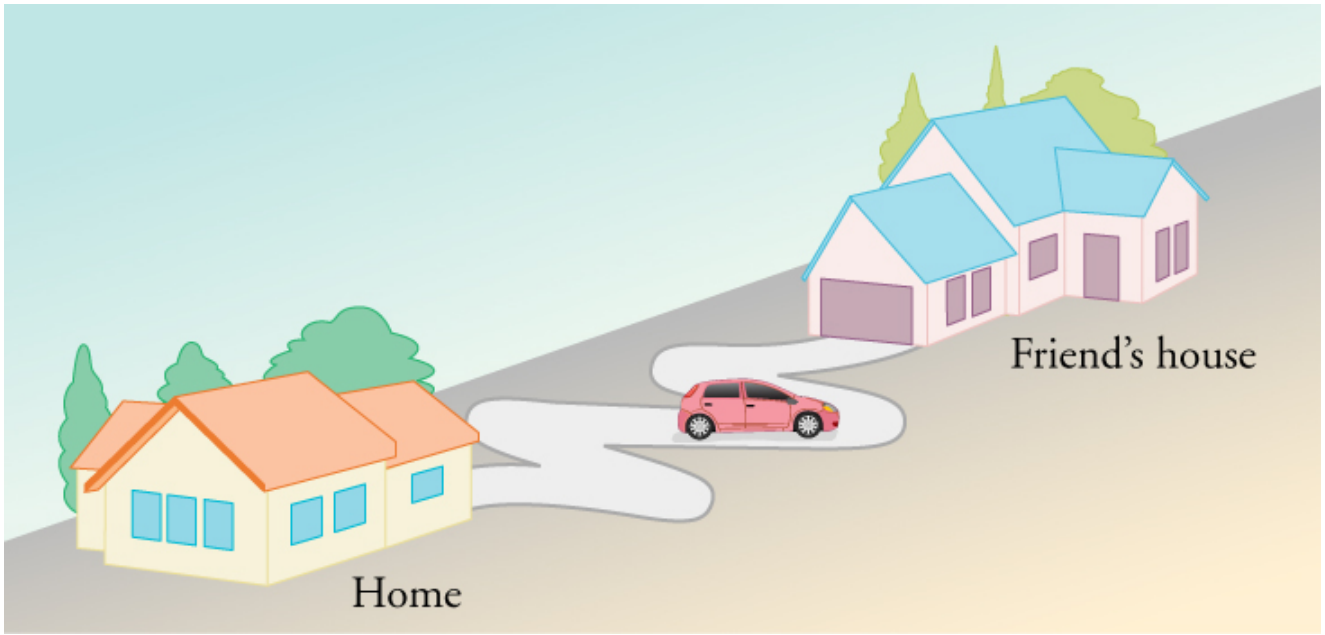

Figure: Short line is displacement. Curved path is distance.

Distance $\geq$ Displacement (always!)

2.1 The Round Trip

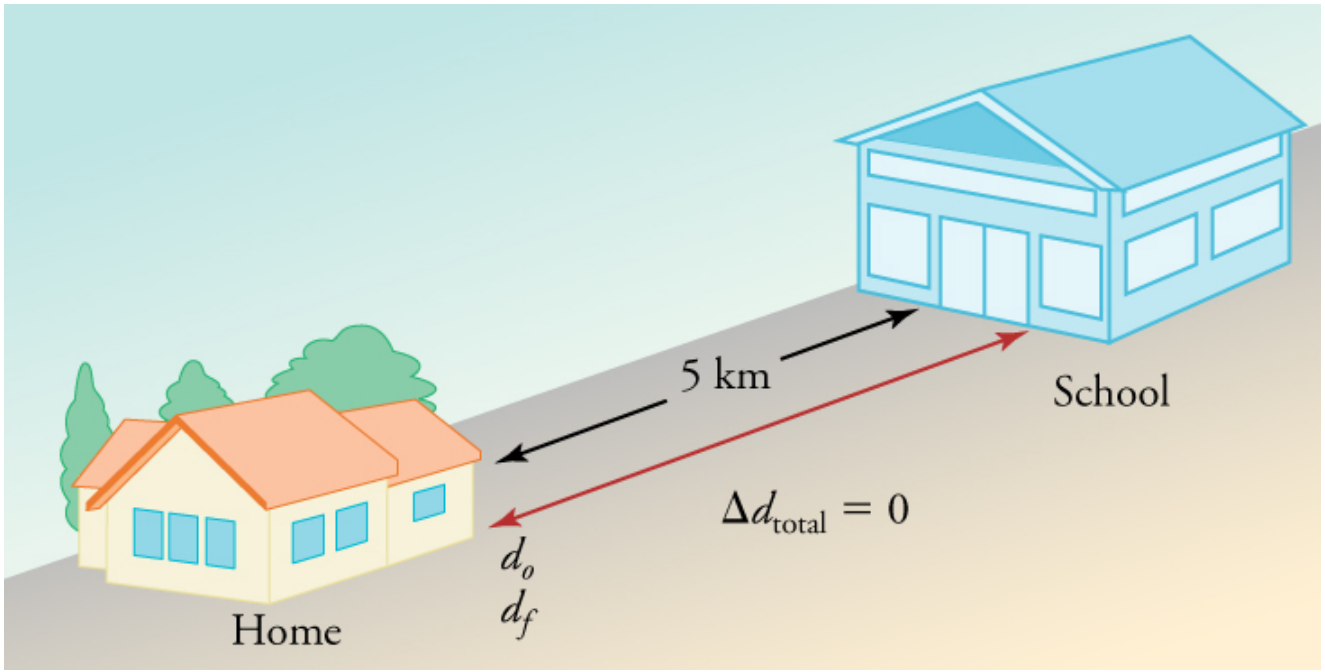

Figure: Drive to school (5 km) and back home (5 km)

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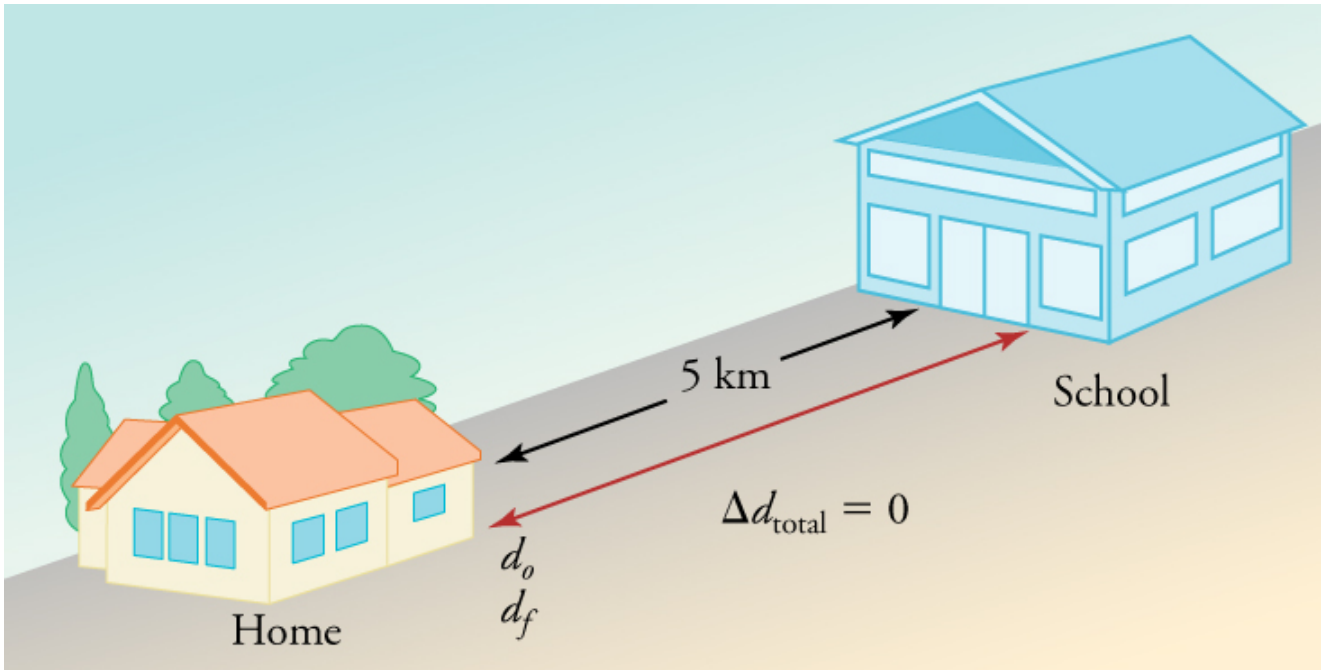

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Distance: 10 km

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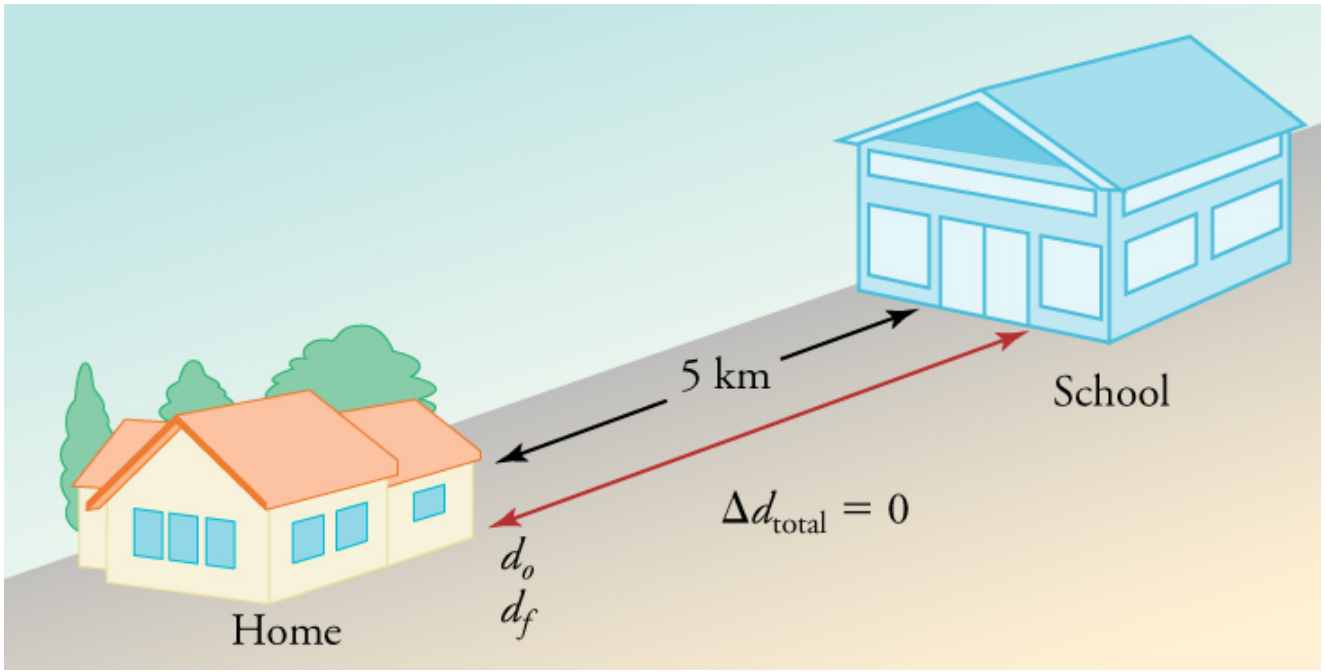

Figure: Drive to school (5 km) and back home (5 km)

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

2.1 Scalars vs. Vectors

Scalar

Magnitude only

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Examples:

- Distance
- Speed
- Time
- Temperature
- Mass

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Magnitude AND direction

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Examples:

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Vector

Magnitude AND direction

Examples:

- Displacement
- Velocity
- Force
- Acceleration

2.1 Displacement Equation

Calculating Displacement

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

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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Smart Choices

Choose origin and direction to make calculations easiest.

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

Attempt: The Cyclist

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.

Compare: The Cyclist

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?

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Name wheel: One pair share your approach.

Reveal: The Cyclist Solution

Self-correct in a different color:

Setup: Choose east = positive, west = negative

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(a) Displacement:

$$\Delta \mathbf{d} = \mathbf{d}_f - \mathbf{d}_0 = -1 \text{ km}$$

(or 1 km west)

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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:

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

2.1 The Mars Probe Disaster

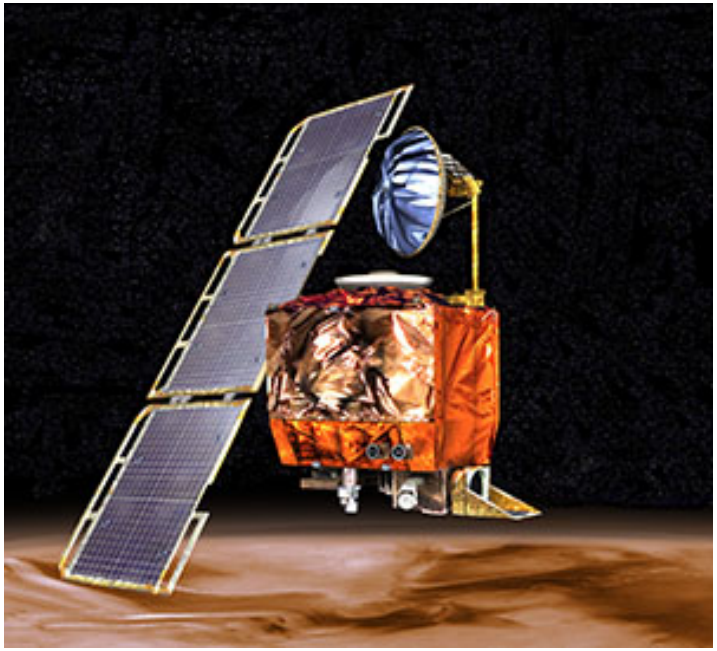

Figure: Mars Climate Orbiter, 1998

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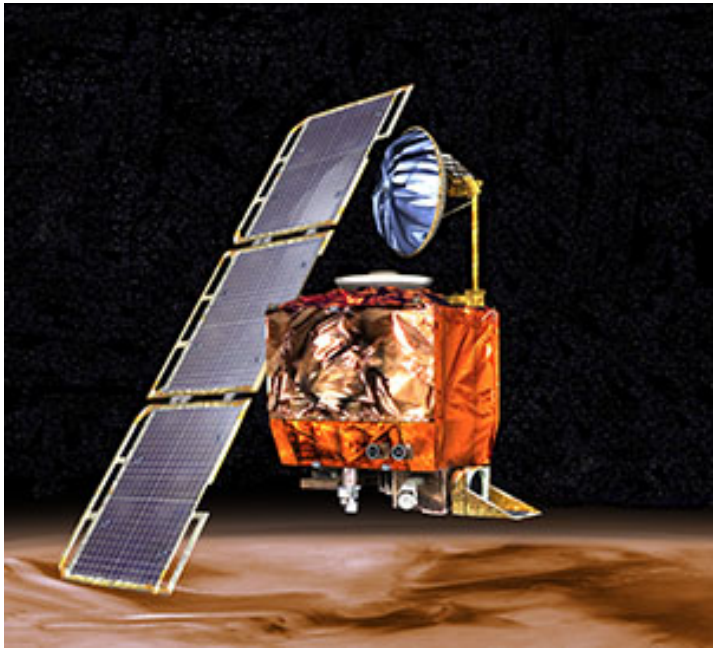

Figure: Mars Climate Orbiter, 1998

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

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

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- **2.2:** Relate displacement and average velocity

2.2 What Is Speed?

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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

$$\boxed{v_{\text{avg}} = \frac{\text{distance}}{\text{time}}}$$

Average speed equals total distance divided by total time.

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Rearranged:

$$\text{distance} = v_{\text{avg}} \times \text{time}$$

$$\text{time} = \frac{\text{distance}}{v_{\text{avg}}}$$

2.2 Average vs. Instantaneous Speed

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Example: Car travels 150 km in 3.2 hours

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Instantaneous speed: Speed at a specific instant

Real-World

Your car's speedometer shows instantaneous speed, not average.

2.2 Round Trip Speed Problem

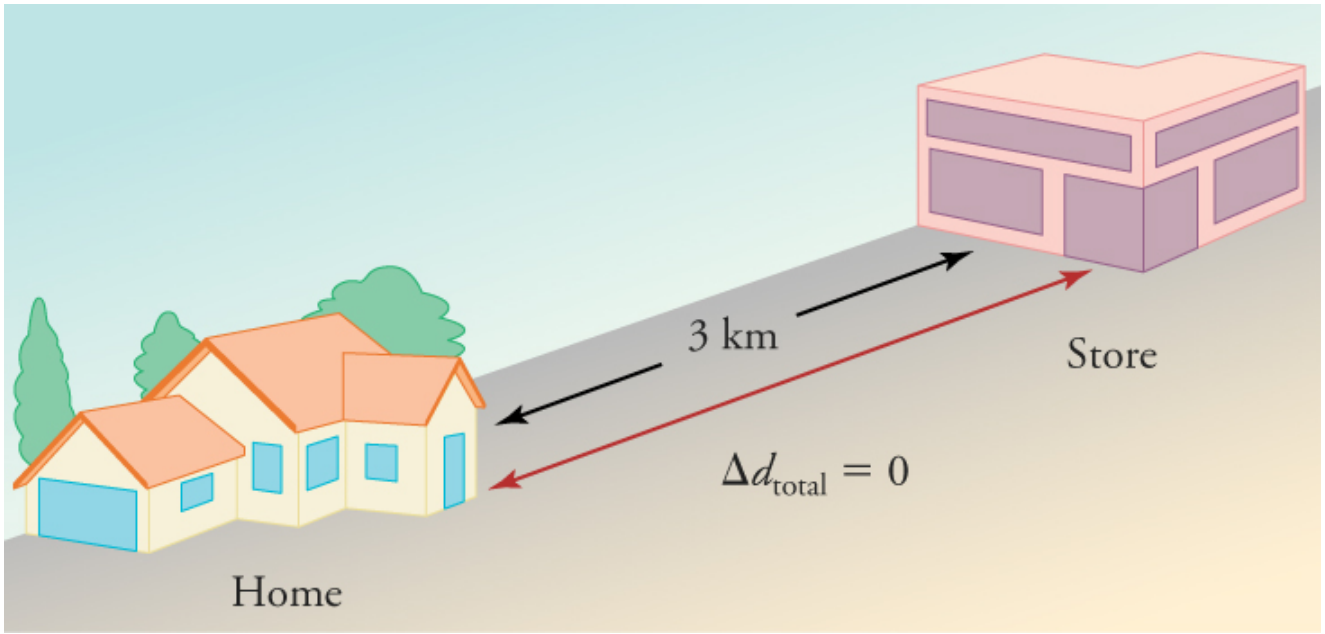

Figure: 30-minute round trip, 6 km total

2.2 Round Trip Speed Problem

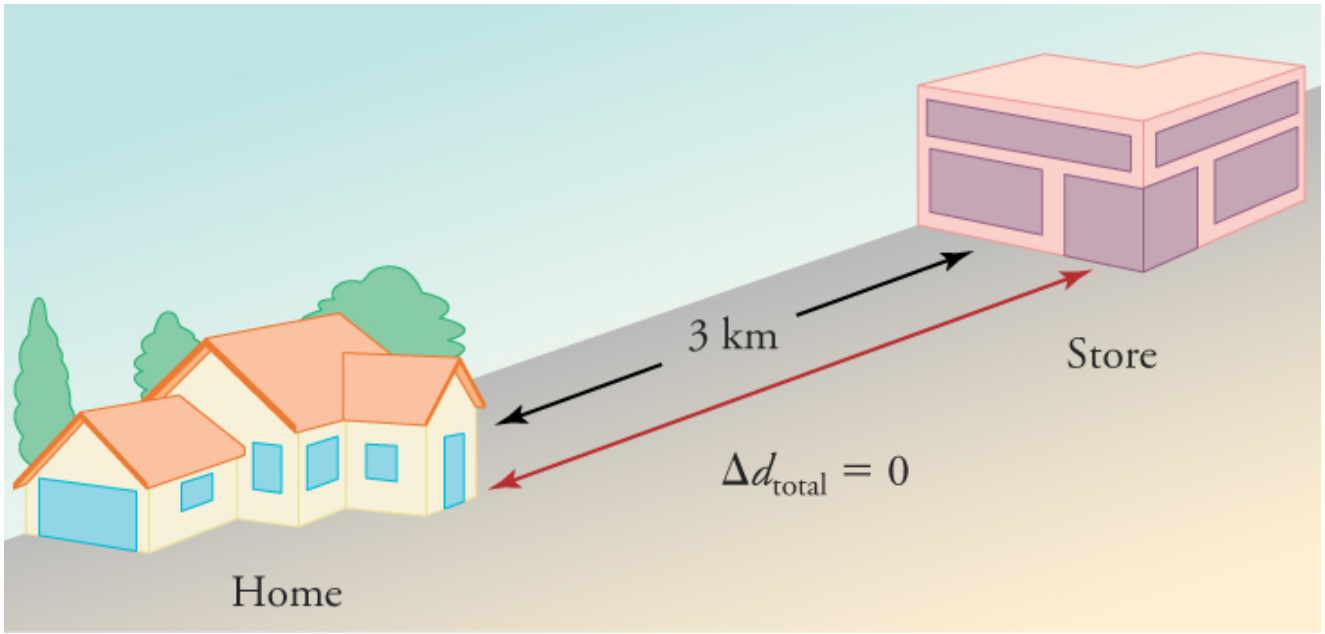

Figure: 30-minute round trip, 6 km total

Average speed: $\frac{6 \text{ km}}{0.5 \text{ h}} = 12 \text{ km/h}$
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?
3. What units did you get?
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Given:

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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:

- $\mathbf{v}$ = velocity (vector, includes direction)
- v = speed (scalar, magnitude only)

2.2 Average Velocity

Universal Law: Rate of Displacement

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

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)

2.2 Speed vs. Velocity

Speed (Scalar)

- Uses distance
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- Example: 50 km/h

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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."

Attempt: The Student

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.

Compare: The Student

Turn and talk (2 min):

1. What formula did you use?
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.

Reveal: The Student Solution

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Given:

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Given:

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

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)

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Average velocity: Over a time interval

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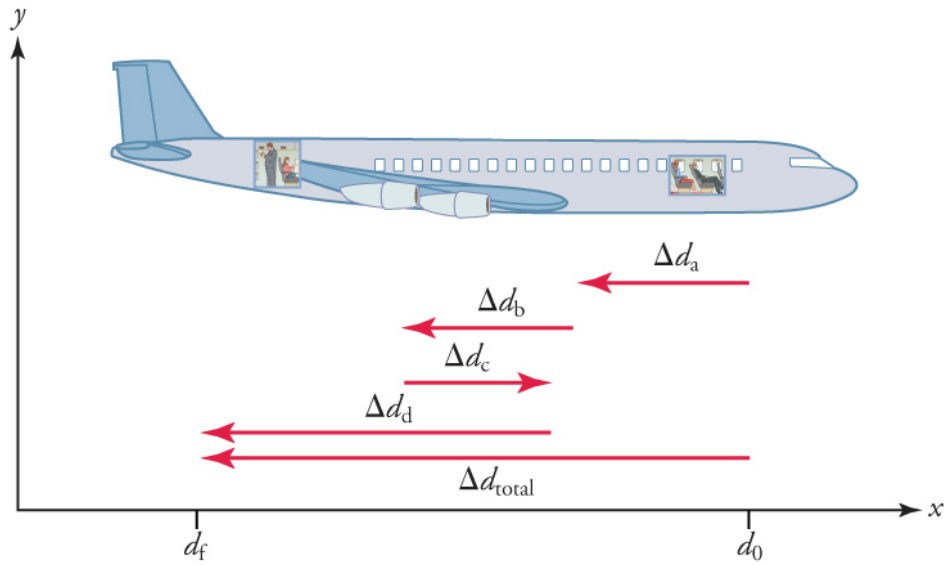

Figure: Airplane passenger velocity at different segments

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Instantaneous velocity: At a specific instant in time

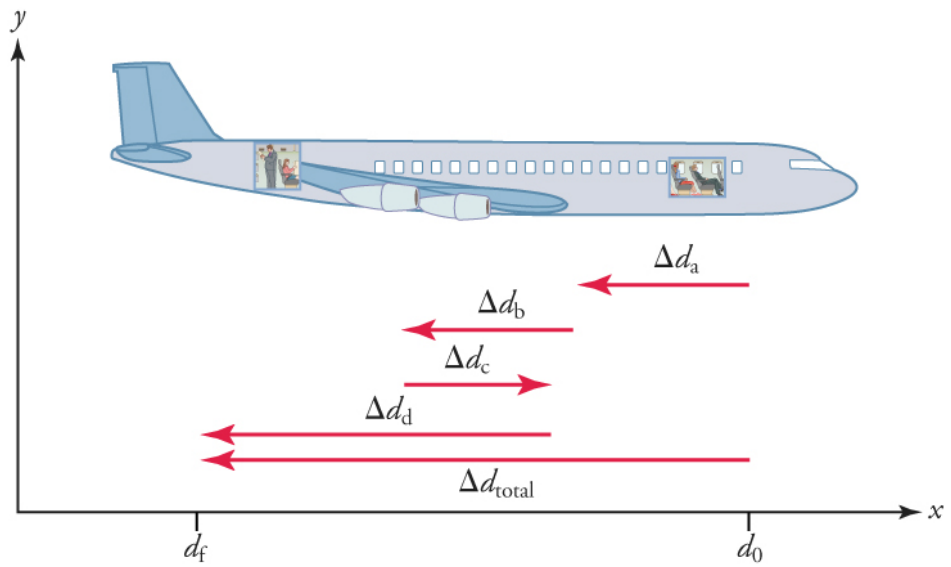

Figure: Airplane passenger velocity at different segments

If velocity is constant, instantaneous = average.

What You Now Know

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4. Displacement = final position - initial position
5. Average speed = distance / time

What You Now Know

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

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

$$v_\mathrm{avg} = \frac{\text{distance}}{\text{time}} \tag{2}$$

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

Remember:

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

Homework

Complete the assigned problems

posted on the LMS