Relative Motion

PH11-8

ORIENTATION

Lesson goal: build accurate physics fluency for relative motion and use that fluency to support clear HSC-style scientific writing.

This page is materialised into the MentorMind course shell from existing teaching, textbook, and eduKG material. Use it as the main lesson surface; use the tutor for targeted repair, worked examples, and concise writing feedback.

SYLLABUS INQUIRY QUESTION

- How is the motion of an object moving in a straight line described and predicted?

From The Feynman Lectures on Physics, Vol I, Chapter 15:

Motion is always measured relative to a chosen frame. Changing the frame changes the numbers, but it does not change the physics.

LEARNING OBJECTIVES

- Define relative position and relative velocity.
- Solve one-dimensional relative motion problems.
- Apply vector subtraction to two-dimensional relative motion.
- Interpret motion from different reference frames.

CONTENT

Relative velocity in one dimension

Relative velocity compares two objects moving along the same line:

$$v_{AB} = v_A - v_B$$

This reads as "the velocity of A **relative to** B".

v_{AB} means "velocity of A as observed from B" or "velocity of A relative to B"

Interactive: One-Dimensional Relative Motion

Consider two cars on a highway. Their relative velocity determines how quickly the gap between them changes.

Example: Car A at 25 m/s, Car B at 18 m/s (both east)

- Relative velocity: $v_{AB} = 25 - 18 = 7$ m/s
- Car A approaches Car B at 7 m/s

Relative velocity in two dimensions

Vectors are subtracted component-wise. The relative velocity points from the observer to the object being described.

$$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$$

Interactive: Boat and River Current

A classic relative motion problem: a boat crossing a river with current.

Interpreting the diagram:

- Blue vector: boat's velocity relative to water (heading north)
- Green vector: water's velocity relative to ground (current flowing east)
- Red dashed vector: boat's velocity relative to ground (resultant)

Reference frames

A statement about motion is incomplete without a frame. The same motion can be described differently in different frames without contradiction.

All velocity measurements require specifying:

1. **What** is moving
2. **Relative to what** it's being measured

Common Relative Motion Scenarios

SCENARIO	FRAME A	FRAME B	RELATIVE VELOCITY
Overtaking cars	Ground	Slower car	Difference in speeds
Boat in current	Water	Ground	Vector sum
Rain on cyclist	Ground	Cyclist	Vector difference
Aircraft in wind	Air	Ground	Vector sum

WORKED EXAMPLES

Example 1: Overtaking cars

Car A travels at 25 m/s east. Car B travels at 18 m/s east. Find A relative to B.

Solution:

1. $v_{AB} = v_A - v_B = 25 - 18 = 7$ m/s
2. The positive result indicates A moves east relative to B
3. A closes the gap at 7 m/s

Example 2: Boat and current

A boat heads due north at 4.0 m/s relative to the water. The current is 1.5 m/s east. Find velocity relative to the ground.

Solution:

1. Components: $v_x = 1.5$ m/s, $v_y = 4.0$ m/s
2. Speed: $\sqrt{1.5^2 + 4.0^2} = \sqrt{18.25} = 4.3$ m/s
3. Direction: $\tan^{-1}(1.5/4.0) = 20 degrees$ east of north

Example 3: Rain and a moving cyclist

Rain falls vertically at 6.0 m/s. A cyclist rides east at 5.0 m/s. Find the rain velocity relative to the cyclist.

Solution:

The rain's velocity relative to the cyclist is found by vector subtraction:

$$\vec{v}{rain/cyclist} = |vec{v}{rain} - \vec{v}_{cyclist}$$

1. Rain (relative to ground): $v_x = 0, v_y = -6.0$ m/s (downward)
2. Cyclist (relative to ground): $v_x = 5.0$ m/s, $v_y = 0$
3. Rain relative to cyclist: $v_x = 0 - 5.0 = -5.0$ m/s, $v_y = -6.0$ m/s

Result:

- Speed: $\sqrt{5.0^2 + 6.0^2} = 7.8$ m/s
- Direction: $\tan^{-1}(5.0/6.0) = 40 degrees$ from vertical, toward the cyclist (west of vertical)

The rain appears to come from ahead! This is why cyclists lean forward in rain.

Example 4: Head-on collision approach

Two trains approach each other. Train A travels at 30 m/s east, Train B at 25 m/s west.

Solution:

Taking east as positive:

- $v_A = +30$ m/s
- $v_B = -25$ m/s

Relative velocity:

- $v_{AB} = v_A - v_B = 30 - (-25) = 55$ m/s

The trains approach each other at the sum of their speeds.

Interactive: Aircraft Navigation

An aircraft must aim off-course to compensate for wind:

Navigation problem: To fly due north (90 degrees), the pilot must aim slightly west to compensate for the eastward wind.

COMMON MISCONCEPTIONS

- **Misconception:** Relative velocity adds magnitudes. **Correction:** It is a vector difference; direction matters.

- **Misconception:** The faster object always has a positive relative velocity. **Correction:** The sign depends on the chosen frame and direction convention.
- **Misconception:** Reference frames change the laws of motion. **Correction:** They change measurements, not the laws.
- **Misconception:** Objects moving in the same direction have zero relative velocity. **Correction:** Only if they have the same speed in the same direction.

PRACTICE QUESTIONS

Easy (2 marks)

A bus moves at 12 m/s east. A passenger walks at 1.5 m/s east relative to the bus. Find the passenger's speed relative to the ground.

- Correct relative velocity model (1)
- Correct final speed with units (1)

Answer: $v_{pg} = v_{pb} + v_{bg} = 1.5 + 12 = 13.5$ m/s east

Medium (4 marks)

A swimmer aims straight across a river at 1.8 m/s relative to the water. The current flows 1.2 m/s downstream. Find the swimmer's ground velocity and direction.

- Correct vector addition (2)
- Correct speed and direction (2)

Answer:

- $v_x = 1.2$ m/s (downstream), $v_y = 1.8$ m/s (across)
- Speed: $\sqrt{1.2^2 + 1.8^2} = 2.2$ m/s
- Direction: $\tan^{-1}(1.2/1.8) = 34 degrees$ downstream from straight across

Hard (5 marks)

Plane A flies 250 km/h north. Plane B flies 180 km/h east. Determine the velocity of A relative to B.

- Correct vector subtraction setup (2)
- Correct relative speed (2)
- Correct direction description (1)

Solution:

$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$

Components:

- $v_{AB,x} = 0 - 180 = -180$ km/h (west)
- $v_{AB,y} = 250 - 0 = 250$ km/h (north)

Relative speed:

- $v_{AB} = \sqrt{180^2 + 250^2} = \sqrt{94900} = 308$ km/h

Direction:

- $\theta = \tan^{-1}(180/250) = 36 degrees$ west of north

Answer: 308 km/h at 36 degrees west of north

From B's perspective, A appears to move northwest.

MULTIPLE CHOICE QUESTIONS

Test your understanding with these interactive questions:

SUMMARY

- Relative motion compares objects using a chosen frame.
- One-dimensional problems use signed subtraction.
- Two-dimensional problems require vector subtraction.
- Clear frame statements prevent sign and direction errors.

SELF-ASSESSMENT

Check your understanding:

After studying this section, you should be able to:

- [ ] Explain what "velocity of A relative to B" means
- [ ] Calculate relative velocity in one dimension
- [ ] Apply vector subtraction for two-dimensional relative motion

- [ ] Solve boat-and-river problems
- [ ] Describe motion from different reference frames

MODULE 1 COMPLETE

Congratulations on completing Module 1: Kinematics!

- Motion in a straight line (displacement, velocity, acceleration)
- Graphical analysis of motion
- SUVAT equations for constant acceleration
- Vector operations in two dimensions
- Relative motion between objects

SCIENTIFIC WRITING AND EXAM SUPPORT

When answering questions from this lesson, separate:

- the physical quantity being discussed,
- the model or law being applied,
- the mathematical relationship, including units,
- the conclusion in words.

For explanation questions, write in the pattern: **claim -> physics reason -> consequence**. For calculation questions, state the formula, substitute with units, calculate, then interpret the answer.

MAINTENANCE LOOP

One-minute retrieval:

1. State the key law, model, or relationship used in this lesson.
2. Identify one common misconception that would lead to a wrong answer.
3. Write one sentence that links the calculation or evidence back to the physical meaning.

STUDENT WORKING