Relative Velocities

Unit: Kinematics (Motion) in One Dimension

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 1.4.B, 1.4.B.1, 1.4.B.2, 1.4.B.2.i, 1.4.B.2.ii

Mastery Objective(s): (Students will be able to…)

- Explain how relative velocity depends on both the motion of an object and the motion of the observer
- Calculate relative velocities.

Success Criteria:

- Explanations account for observed behavior.

Language Objectives:

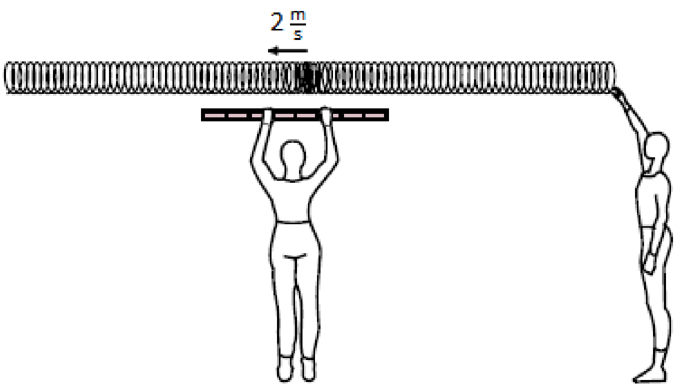
- Explain why velocities are different in different reference frames.

Tier 2 Vocabulary: relative, reference frame

Notes:

Because the observation of motion depends on the reference frames of the observer and the object, calculations of velocity need to take these into account.

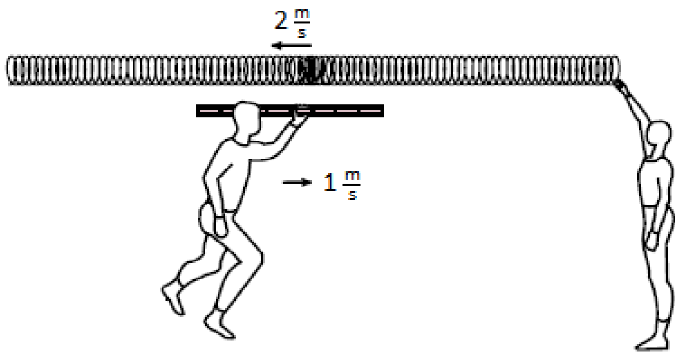
Suppose we set up a Slinky and a student sends a compression wave that moves with a velocity of $2\,\frac{\text{m}}{\text{s}}$ along its length:



A second student holds a meter stick and times how long it takes the wave to travel from one end of the meter stick to the other. The wave would take 0.5 s to travel the length of the meter stick, and the student would calculate a velocity of $\frac{1\,\text{m}}{0.5\,\text{s}} = 2\,\frac{\text{m}}{\text{s}}$.

Use this space for summary and/or additional notes:

Suppose instead that the student with the meter stick is running with a velocity of $1\,\frac{m}{s}$ toward the point of origin of the wave:



In this situation, you could use the velocities of the moving student and the wave and solve for the amount of time it would take for the wave and the end of the ruler to reach the same point. The calculation for this would be complicated, and the answer works out to be 0.33 s, which gives a velocity of $3\,\frac{m}{s}$.

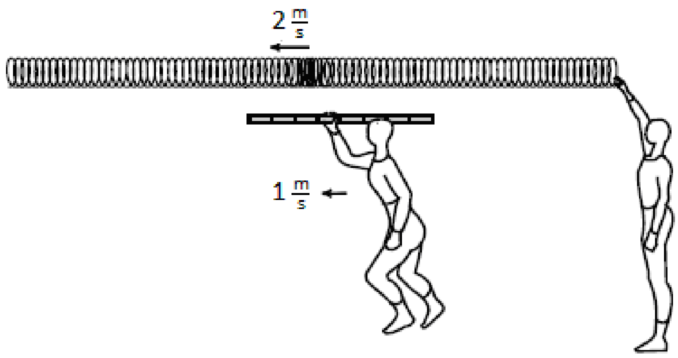
The easier way to calculate this number is to realize that the velocity of the wave relative to the moving student is simply the sum of the velocity vectors. The velocity of the wave relative to the moving student is therefore $2\,\frac{m}{s}+1\,\frac{m}{s}=3\,\frac{m}{s}$.

This $3\,\frac{m}{s}$ is called the relative velocity, specifically the velocity of the wave relative to the moving student.

relative velocity: the apparent velocity of an object relative to an observer, which takes into account the velocities of both the object and the observer. When the object and the observer are both moving, the relative velocity is sometimes called the *approach velocity*.

Use this space for summary and/or additional notes:

Suppose instead that the student is running away from the point of origin (*i.e.,* in the same direction as the wave is traveling) with a velocity of $1\,\frac{m}{s}$:



Now the relative velocity of the wave is $2\,\frac{m}{s} - 1\,\frac{m}{s} = 1\,\frac{m}{s}$ relative to the moving student.

If the student and the wave were moving with the same velocity (magnitude and direction), the relative velocity would be zero and the wave would appear stationary to the moving student.

Use this space for summary and/or additional notes:

Homework Problems

1. **(M)** A river is flowing at a rate of $2\,\frac{m}{s}$ to the south. Jack is swimming downstream (southward) at $2\,\frac{m}{s}$ relative to the current, and Jill is swimming upstream (northward) at $2\,\frac{m}{s}$ relative to the current.

   a. What is Jack's velocity relative to Jill?

   Answer: $4\,\frac{m}{s}$ southward

   b. What is Jill's velocity relative to Jack?

   Answer: $4\,\frac{m}{s}$ northward

   c. What is Jack's velocity relative to a stationary observer on the shore?

   Answer: $4\,\frac{m}{s}$ southward

   d. What is Jill's velocity relative to a stationary observer on the shore?

   Answer: zero

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2. **(S)** A small airplane is flying due east with an airspeed (*i.e.,* speed relative to the air) of $125\,\frac{m}{s}$. The wind is blowing toward the north at $40\,\frac{m}{s}$. What is the airplane's speed and heading relative to a stationary observer on the ground? (*Hint: this is a vector problem.*)

   Answer: $131\,\frac{m}{s}$ in a direction of 17.7° north of due east

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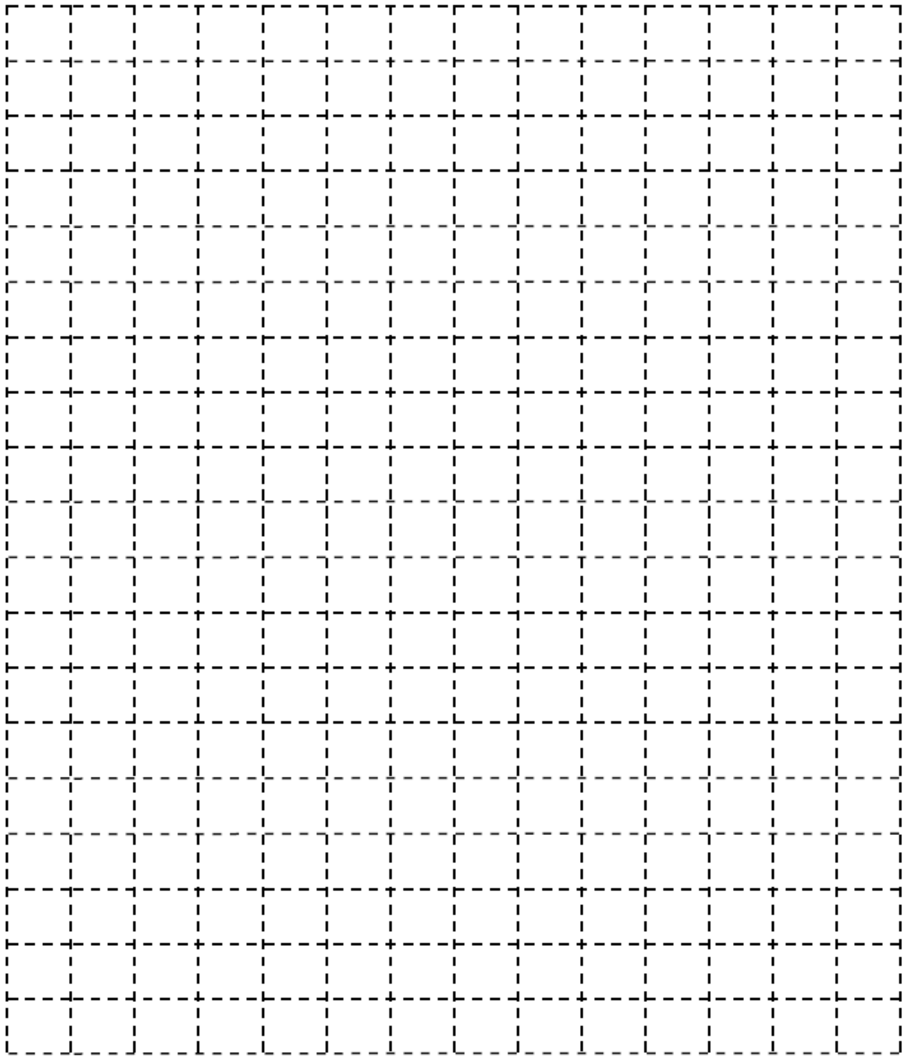
3. **(M)** A ship is heading 30° north of east at a velocity of $10\frac{m}{s}$. The ocean current is flowing north at $1\frac{m}{s}$. A man walks across the ship at $2\frac{m}{s}$ in a direction perpendicular to the ship (30° west of north).

   Add the velocity vectors by drawing them on the grid below to show the velocity of the man relative to a stationary observer. (*Note: you do not have to calculate the numerical value.*)



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