2. Speed and Velocity

Driving Questions

What is meant when a person refers to the speed of an object rather than its velocity. What makes those two quantities different? What makes them similar? In this lab, we explore these questions and build a fundamental understanding of the similarities and differences between speed and velocity.

Background

When a police officer pulls you over for driving too fast, it is not often that he or she is concerned about the velocity of your car, but rather, the speed at which you were traveling. A basic and important difference between speed and velocity is that velocity is a vector quantity, implying magnitude and direction, while speed is simply a scalar magnitude without direction.

Speed is defined as the change in distance, regardless of the direction of that distance, divided by the change in unit of time it took to travel that distance. How fast something is going?

$$\text{Speed} = \frac{\Delta\text{distance}}{\Delta\text{time}}$$

Velocity is generally defined as the unit displacement *in a specific direction* or change in position divided by the unit of time:

$$\text{Velocity}_x = \frac{\Delta\text{position}_x}{\Delta\text{time}}$$

How are speed and velocity related? Think of the velocity of an object as simply the combination of the object's speed and its direction.

Materials and Equipment

For each student or group:

- Data collection system
- Dynamics track
- Dynamics track end stop
- Motion sensor
- Dynamics cart

Safety

Add these important safety precautions to your normal laboratory procedures:

- The cart carries speed and momentum, so be careful not to pinch fingers between the moving cart and the end stop when catching it.
- The plunger on the dynamics cart may release accidentally, so be careful not to hold the cart near anything breakable when the plunger is loaded.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
Find the average velocity for the trip toward the bumper.	Draw your prediction on your data collection system.	Start data collection.	Gently push the cart toward the bumper.	Assemble the equipment with the Dynamics cart just over 15 cm from the motion sensor.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Attach the motion sensor to one end of your track with the sensor's sensing element pointing down the length of the track. Make certain that the switch on the top of the motion sensor is set to the cart icon. 

3. ☐ Connect the end stop to the other end of the track.

4. ☐ Connect the motion sensor to the data collection system. �(2.1)

5. ☐ Display Position on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

6. ☐ The concept behind this setup is to push the cart so that it moves away from the motion sensor, increasing its position relative to the motion sensor, until it collides with the end stop and returns, measuring the position, velocity, and speed of the cart the entire time. If you or your lab partners aren't touching the cart as it travels, what do you think a graph of its Position versus Time will look like? Use the data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

7. ☐ What would happen to the cart if there were no bumper on the track?

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8. ☐ Prepare the following calculation on the data collection system: �(10.3)

Speed = abs(Velocity)

where Velocity is the velocity measurement from the motion sensor.

9. ☐ Display Speed on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

10. ☐ Given the motion described above, what do you think a graph of its Speed versus Time will look like? Use your data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

11. ☐ As was mentioned in the background section, velocity is a vector quantity that implies direction. If the motion sensor measures 2.5 m/s as the velocity of a constant speed cart moving away from the sensor, what would the sensor measure if the same cart was moving towards the sensor? Justify your answer.

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12. ☐ Display Velocity on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

13. ☐ Given the motion described above, what do you think a graph of Velocity versus Time will look like? Use the data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

14. ☐ Return to the graph of Position versus Time.

15. ☐ Ensure that the sampling rate of the data collection system is at least 20 samples per second. �(5.1)

Collect Data

16. ☐ Place the cart on the track slightly more than 15 cm from the motion sensor such that either the magnets or extended plunger are facing the bumper so that the cart will rebound from the end of the track.

    Note: If you are not using the plunger to collide with the end stop, it is best to press the plunger all the way in and lock it in place so it is out of the way.

17. ☐ Start data collection. �(6.2)

18. ☐ Give the cart a push to start it moving toward the bumper.

19. ☐ Allow the cart to travel down the track, collide with the bumper and return, but catch it before it reaches its initial position.

20. ☐ Stop data collection. �(6.2)

21. ☐ Sketch your Position versus Time, Speed versus Time, and Velocity versus Time graphs on the blank graph axes provided in the Data Analysis section.

Analyze Data

22. ☐ On the Position versus Time graph, select a point just after you released the cart and another point just before the cart collides with the bumper. �(7.1.4)

23. ☐ Use the data collection system to find the difference between the data points you have selected. �(9.2)

24. ☐ Identify the points you used on your sketch of Position versus Time in the Data Analysis section.

25. ☐ Record the difference in time and the difference in position in Table 1 in the Data Analysis section.

26. ☐ From our definition of speed, calculate the speed for this leg of the journey, and record it in Table 1 in the Data Analysis section.

27. ☐ Describe the shape of the data plot in the interval you have selected.

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28. ☐ On the graph of Speed versus Time, select the same region you selected on the Position versus Time graph using the time values as your guide. �(7.1.4)

29. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

30. ☐ On the graph of Velocity versus Time, select the same region you selected on the Position versus Time graph using the time values as your guide. �(7.1.4)

31. ☐ Find the average value for velocity for the data you selected, and record it in the table in the Data Analysis section. �(9.4)

32. ☐ On the Speed versus Time graph, select a point just after the cart collides with the bumper and another point just before you catch the cart. Use the data collection system to select this part of the data plot. �(7.1.4)

33. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

34. ☐ Identify the points you used on the sketch of Speed versus Time in the Data Analysis section.

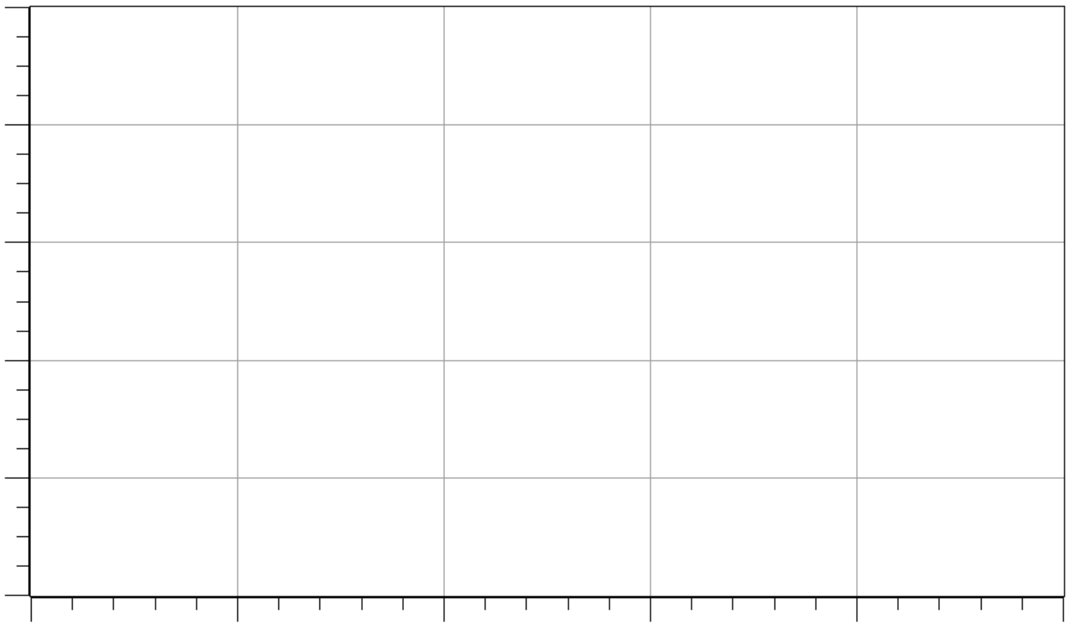
35. ☐ On the graph of Velocity versus Time, select the same region you selected on the speed graph using the time values as your guide. �(7.1.4)

36. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

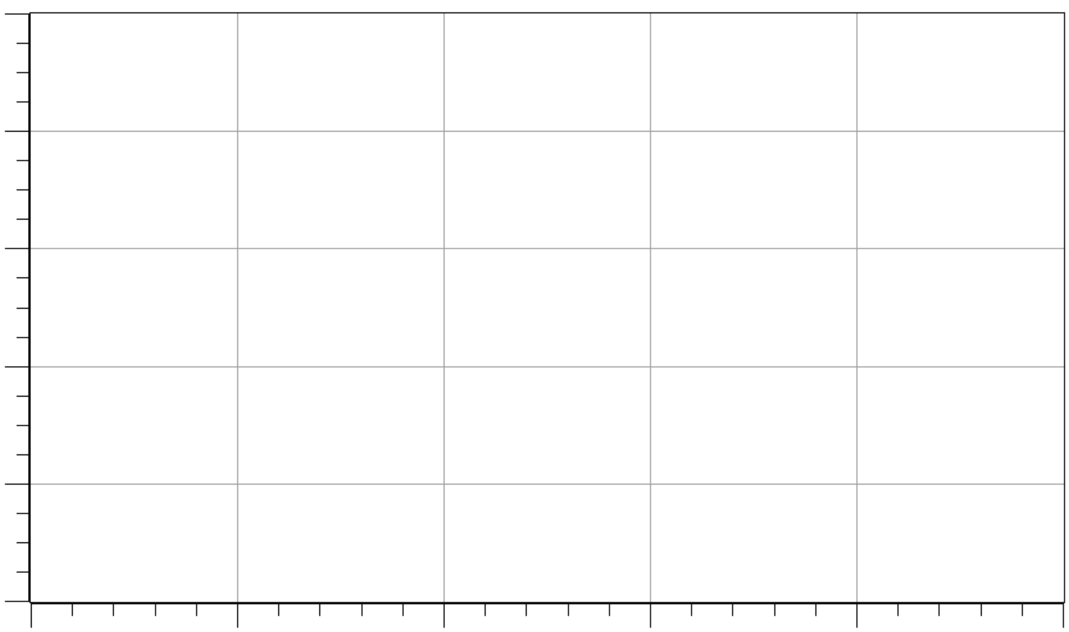
Data Analysis

1. ☐ In the first three spaces provided, sketch your prediction graphs of Position versus Time, Speed versus Time and Velocity versus Time for one trip down the track and back.

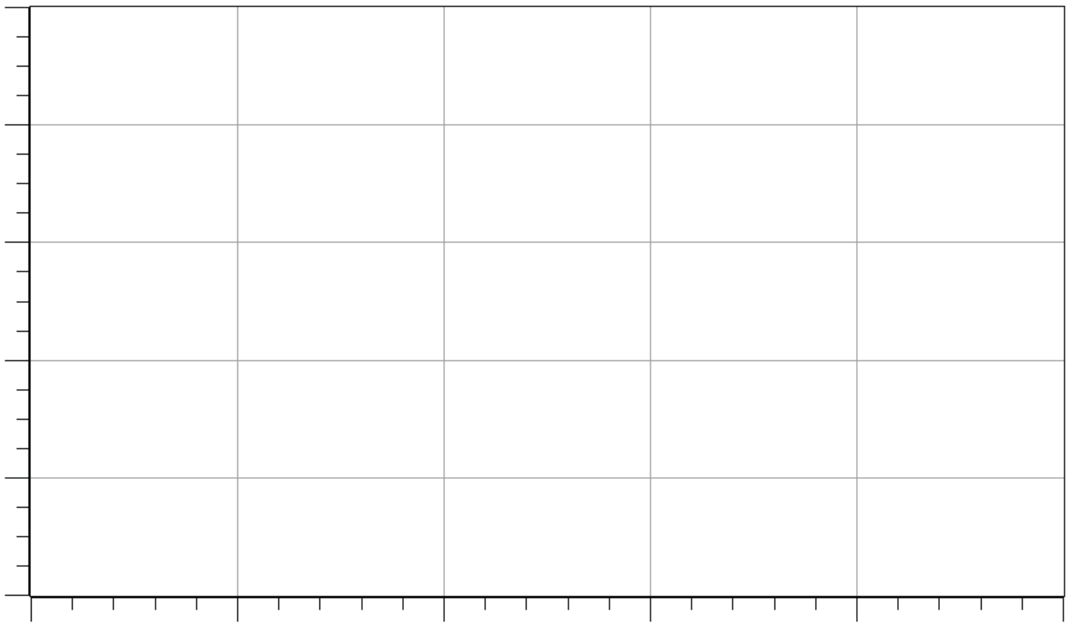
Position versus Time Prediction



Speed versus Time Prediction

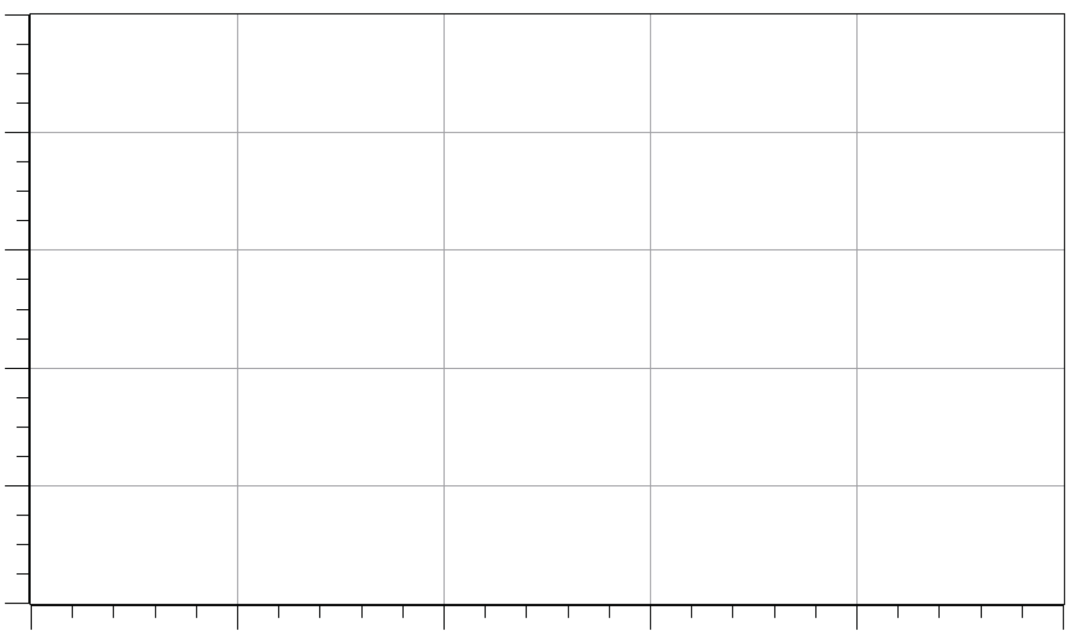


Velocity versus Time Prediction

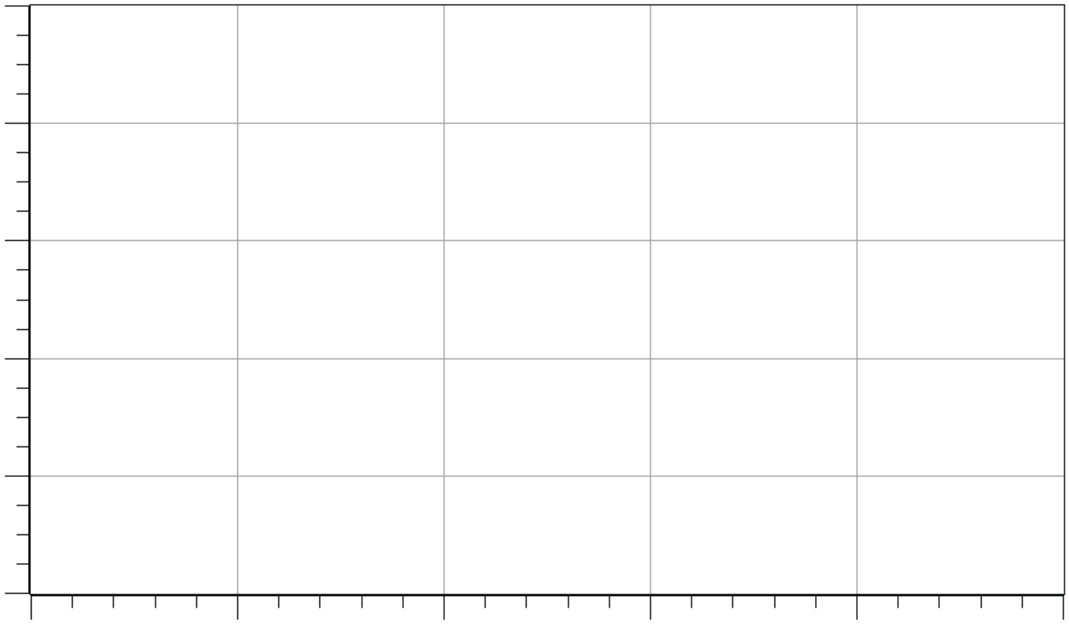


2. ☐ In the next three spaces provided, sketch your data from your graphs of Position versus Time, Speed versus Time and Velocity versus Time for one trip down the track and back.

Position versus Time



Speed versus Time



Velocity versus Time

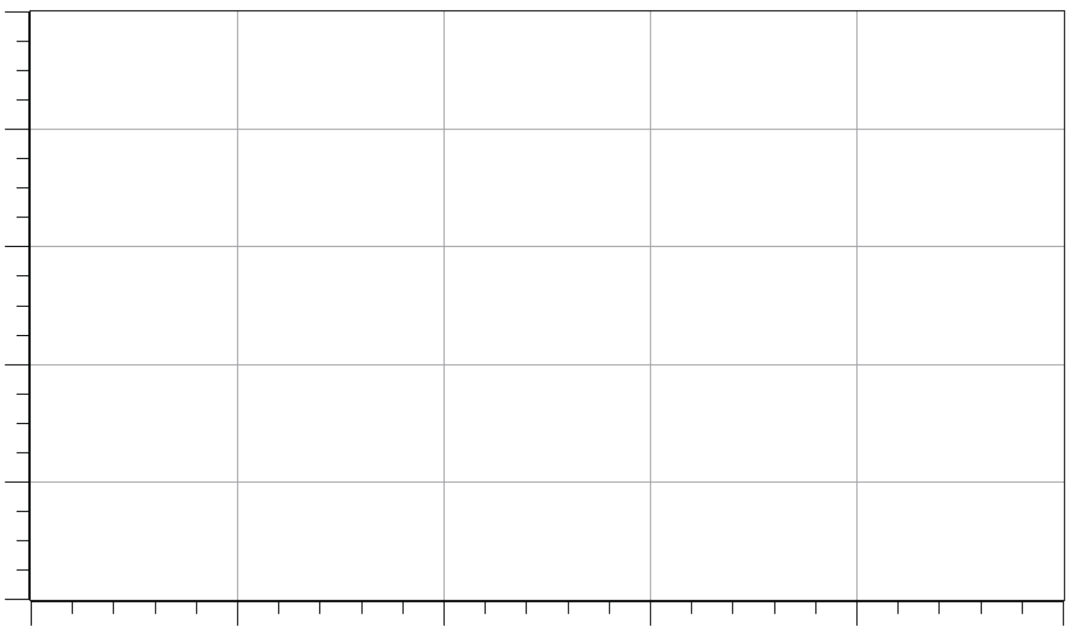


Table 1: Data

Parameter	Values
Difference in position moving away from the motion sensor	
Difference in time moving away from the motion sensor	
Calculated speed moving away from the motion sensor	
Average speed moving away from the motion sensor	
Average velocity moving away from the motion sensor	
Average speed moving toward from the motion sensor	
Average velocity moving toward from the motion sensor	

Analysis Questions

1. How does the value you calculated for speed moving away from the motion sensor compare to the value of the average speed over the same interval?

2. How do your values of speed and velocity moving away from the motion sensor compare to your values of speed and velocity moving toward the motion sensor?

3. **How does your prediction graph of Position versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?**

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4. **How does your prediction graph of Speed versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?**

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5. **How does your prediction graph of Velocity versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?**

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6. **Describe some of the major differences between your graph of Speed versus Time and Velocity versus Time, and explain why those differences exist.**

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7. **Describe how you think the Velocity versus Time graph would be different if the cart had an initial speed that was twice as large as the initial speed used in your experiment.**

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8. You may have noticed that the speed of the cart slightly decreased as the cart moved along the track, both moving away from the motion sensor and moving toward the motion sensor. What do you thing would account for this decrease?

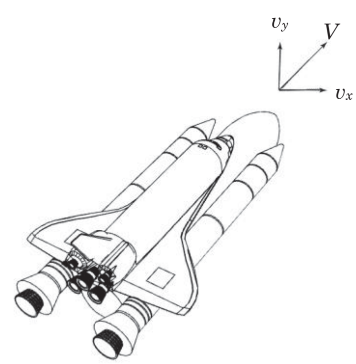
Synthesis Questions

Use available resources to help you answer the following questions.

1. Imagine you are in a car driving on a highway and notice that the speedometer was constant at 65 miles per hour for several miles. Would this indicate that the speed of the car was constant during that distance, or the velocity of the car was constant? Justify your answer.

2. Two trains pass each other on opposing tracks; one train is traveling north at 105 km/hr while another train is traveling south at 85 km/hr. What is the difference between their velocities? What is the difference between their speeds? Show your work.

3. When a space shuttle is launched, it approaches the upper atmosphere at a very specific angle to help it safely reach orbit. At the point it reaches orbit, the shuttle is traveling at some speed s, which can be determined from the sum of the shuttle's two component velocity vectors, v_x and v_y. If v_x = 15,768 km/hr and v_y = 11,149 km/hr, what is the shuttle's speed s?



4. **The average velocity of an object is defined as the total displacement of an object (from its original position) divided by the time elapsed during that displacement.**

$$\bar{\mathbf{v}} = \frac{\textit{final displacement}}{\textit{total time}}$$

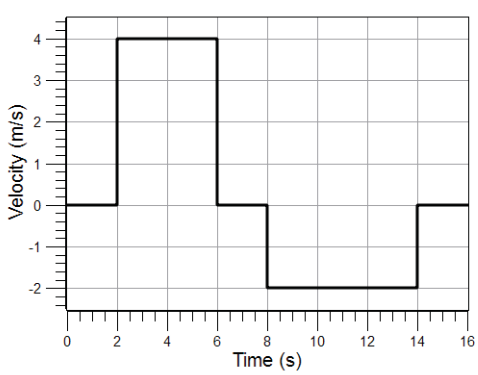
a. **If a car drives all the way around a city block at 30 mi/hr and ends 10 minutes later at the same point it began, what is the average velocity of the car?**

b. **If a car drives north at 65 mi/hr for 48 minutes, turns right and drives east at 45 mi/hr for 23 minutes; and then turns right again and drives south at 30 mi/hr for an hour and 44 minutes, and stops. What was the car's average velocity during that that trip?**

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **The graph below shows the velocity of a particle as a function of time. Assume that the particle is traveling in a straight line. Use the graph to determine the particle's total displacement and average velocity.**



A. 4 m; 0.25 m/s

B. –4 m; –0.25 m/s

C. 26 m; 2.60 m/s

D. 26 m; 1.63 m/s

2. **Average speed is defined as the total distance an object travels divided by the time it took to travel that distance. If a jet flies 2,000 miles from San Francisco to Chicago in 5 hours, refuels for an hour, and then flies 700 miles from Chicago to Washington DC in 2 hours, what was the average speed of the jet for the entire trip?**

- **A.** 386 mi/hr
- **B.** 443 mi/hr
- **C.** 250 mi/hr
- **D.** 338 mi/hr

3. **What is wrong with this statement?**

"A highway patrol officer traveling east with a constant speed of 70 mi/hr passes a speeding motorist traveling west at 110 mi/hr. To catch the speeder, the officer must first travel 0.25 miles to the next highway exit, turn around, and get back on the freeway then drive at a constant speed of –150 mi/hr for 58 seconds to catch-up with the motorist."

- **A.** The officer will pass the speeder if he/she travels at 150 mi/hr for 58 seconds.
- **B.** The officer's original constant velocity should be negative.
- **C.** Speed cannot be negative.
- **D.** There is nothing wrong with the statement.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

Note to editors: The Key Term Challenge section isn't in the Advanced or AP labs.

1. Although ________________ and velocity are often used in the same context, the two terms are very different. Speed is a ________________ quantity while velocity is a ________________ quantity. Velocity values specify ________________ as well as ________________ while speed simply specifies magnitude. If the speed of an object is known, it is impossible to determine the object's ________________ without knowing the direction the object is traveling.

2. When discussing ________________ speed and average velocity, one must first understand the difference between distance and displacement. If a boomerang follows a circular 42 meters ________________ in 10 seconds and ends at the same point it was thrown, its ________________ traveled is 42 meters but its total ________________ is zero. Furthermore, the boomerang's average ________________ was 4.2 meters/second, and its average ________________is zero.

3. If a ball is initially at ________________(not moving), its ________________and velocity are both zero. If the ball is thrown straight up in the air, it will eventually fall back down to the same ________________it was tossed from, at which point its final ________________is ________________ and ________________to its initial velocity.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2	Paragraph 3
Acceleration	Average	Average
Direction	Continuous	Equal
Magnitude	Direction	Final
Position	Displacement	Opposite
Scalar	Distance	Position
Speed	Path	Rest
Vector	Speed	Speed
Velocity	Velocity	Velocity