Kinematics
Rectilinear Motion, Uniform
Speed and Velocity

CONCEPT EXPLORATION

In this activity we will explore the idea of uniform speed and uniform velocity. The term **uniform** refers to a quantity or concept that does not change. The difference between speed and velocity will be investigated during this exploration activity.

In the last lesson you generated position-time graphs for objects that were at rest at various positions. In order to change their position these objects had to move.

1. How would you describe the shape of the portion of the graph that corresponded to the brief time intervals during which the objects were moving in the previous unit? Were these portions also “flat” lines?

The shape of the graphs during the times that the objects moved will be the focus of this investigation.

Engagement Question

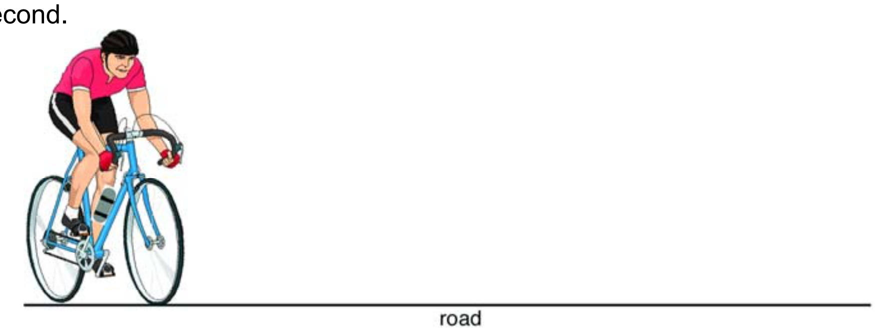
2. What speed do you have as you sit here in our classroom?

The Challenge

You will determine the successive positions of an object moving with uniform velocity at 1-second intervals.

A cyclist moves at a steady speed in a straight line (uniform velocity). His water bottle has sprung a leak so that a drop of water falls to the pavement every second.

3. On the road shown to the right draw the drops of water at the position that they might appear as a result of this cyclist’s motion.



Check your work with your teacher.

At each lab station you will find the following:
Two battery-powered cars, a stopwatch, some masking tape, and a metric ruler

The Investigation

a. Place one of the battery-powered cars on the floor.
b. The student with the stopwatch should count down from three and start the stopwatch calling out the times at 1-second intervals.
c. The student with the car should release the car at the moment that the stopwatch starts.
d. Place pieces of masking tape at the position attained by the car at the end of each second. Do this for 4 seconds.
e.You will need to repeat this process several times until you feel that you have the masking tape in roughly the correct positions for the 1-second intervals.
f. Measure the distance from one piece of tape to the next.

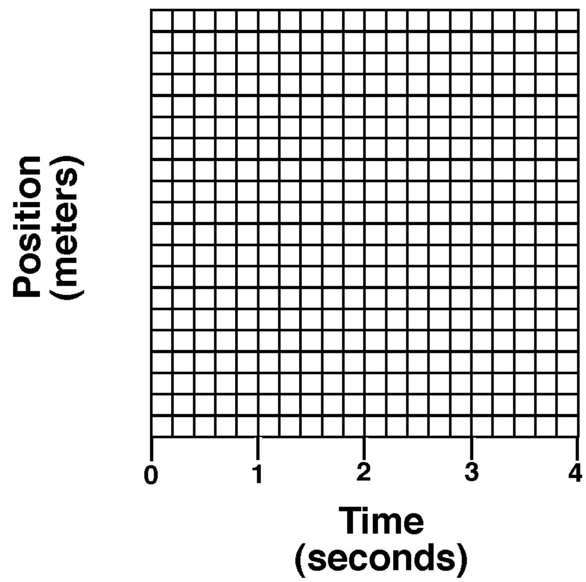
4. Do the distances between successive pieces of tape differ by very much or are they pretty much the same? How do you explain this in terms of the cars motion?

The Challenge

You will draw a position-time graph for an object moving with uniform velocity.

Your Ideas about the Challenge

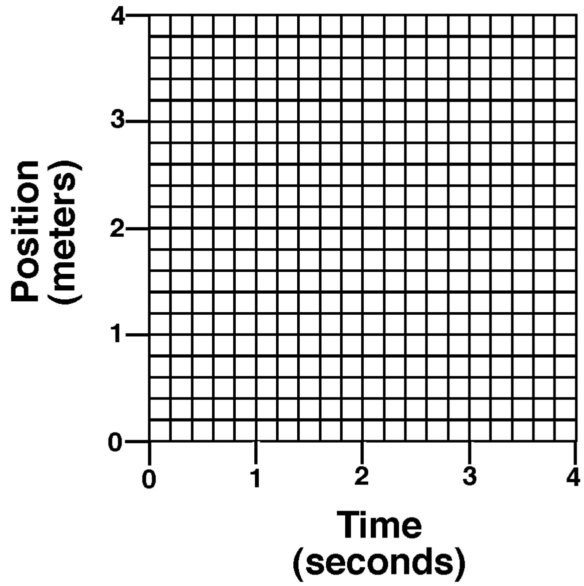
5. On the graph below sketch what you think the position-time graph will look like for an object that is moving forward at a constant rate of speed for a period of 4 seconds.



The Investigation (continued)

a. Place car A approximately 1/2 meter away from the motion detector so that it will move away from the motion detector when it is switched on.
b. Start the graphing program and release the car so that it moves directly away from the motion detector.
c. After 4 seconds stop the graphing program and stop the car.

6. On the grid provided below draw the shape of the graph that you have on the computer display.



7. Describe the shape of the resulting graph. Is it a straight line?

8. How does the shape of the graph drawn above differ from the shape of the graphs that we received for objects at rest? How can you tell from a position-time graph that an object is moving?

9. Evaluate the following student statements about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

Student A
"An object moving at constant speed will also produce a position-time graph that is a straight line. However, unlike an object at rest, the graph of a moving object has a slope."

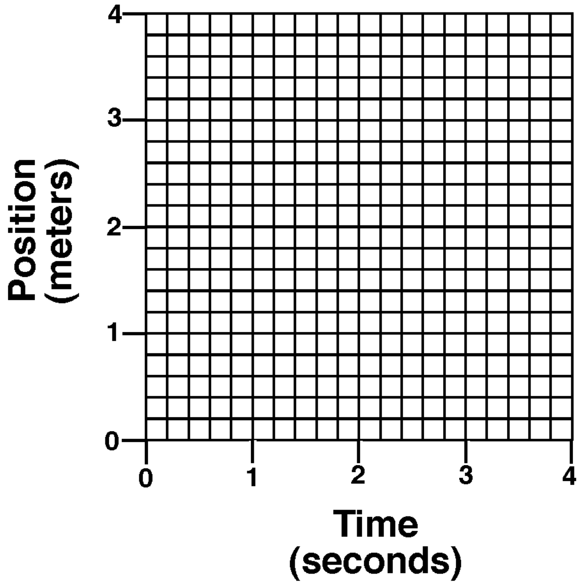
Student B
"An object at rest also has a constant speed. The speed is constantly zero. This is why it produces a position-time graph with zero slope."

Check your work with your teacher. ☐

The Investigation (continued)

a. Place car B approximately 1/2 meter away from the motion detector so that it will move away from the motion detector when it is switched on.
b. Start the graphing program and release the car so that it moves directly away from the motion detector.
c. After 4 seconds stop the graphing program and stop the car.

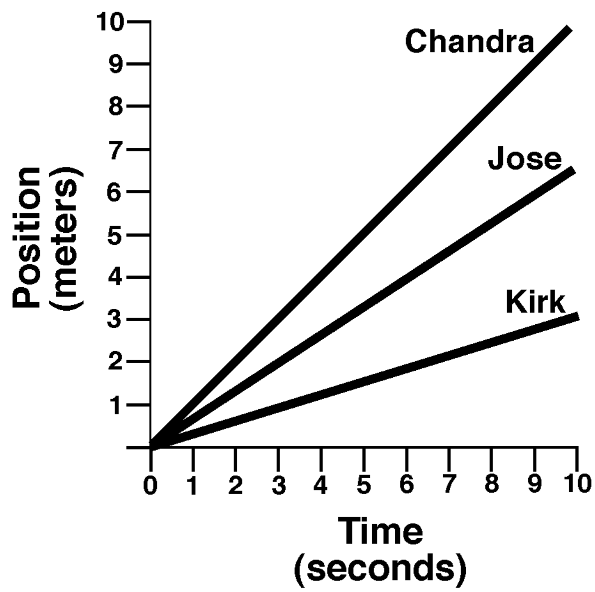
10. On the grid provided below draw the shape of the graph that you have on the computer display. Label this line car B. Draw the graph of car A on this graph as well. Label this line car A.



11. What is different about the shape of the two different graphs? How can you tell from a position-time graph how fast an object is moving?

The position-time graph to the right shows the positions of three different students moving down the hallway at constant speeds.

12. Based on the graph shown above indicate which student is moving the fastest and which student is moving the slowest. Explain how you made your decision.



13. Evaluate the following student statement about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

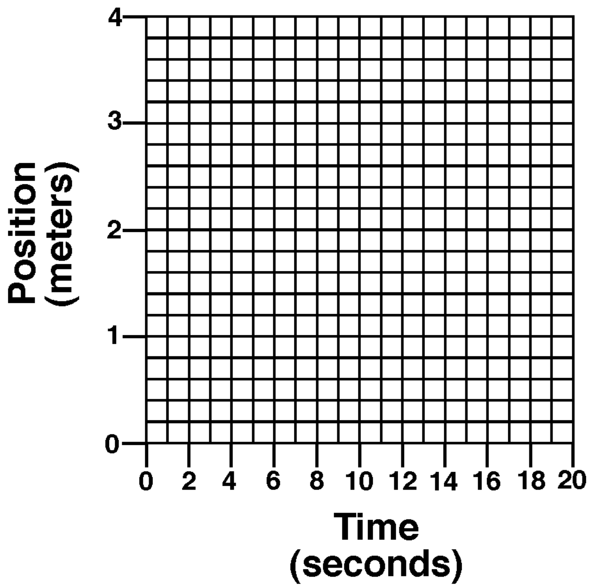
"A faster moving object will produce a position-time graph with a steeper slope. The greater the slope on a position-time graph, the faster the object must be moving."

Check your work with your teacher. ☐

The Investigation (continued)

a. Take one of the cars and place it approximately 2 meters away from the motion detector so that it will move directly towards the detector when it is switched on.
b. Start the graphing program and then release the car.
c. Stop the graphing program when the car is approximately 1/2 meter from the detector and then switch off the car.

14. On the grid provided below draw the shape of the graph that you have on the computer display.



15. What is the difference between the graph for the car approaching the motion detector and the graph of the cars moving away from the detector?

16. How can you tell from a position-time graph the <u>direction</u> that an object is moving?

Velocity can be thought of as speed in a specific direction. If you say the car was moving at 1 m/s, you have described the speed of the car. If you say the car was moving at 1 m/s towards the motion detector, you have described the velocity of the car.
In this activity, negative slope indicated that the car was moving towards the motion detector. Positive slope indicates that the car was moving away from the motion detector. In order to correctly express the velocity of the car you shouldn't just simply say that a velocity was +1 m/s, you should say that the velocity was 1 m/s away from the motion detector.

17. Evaluate the following student statements about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

<u>Student A</u>
"If an object, moving in a particular direction, produces a positive slope on a position-time graph then it will produce a negative slope when it moves in exactly the opposite direction."

<u>Student B</u>
"An object that produces a negative slope on a position-time graph must be moving slower than an object that produces a positive slope. This is because negative numbers are less than positive numbers."

Check your work with your teacher. ☐

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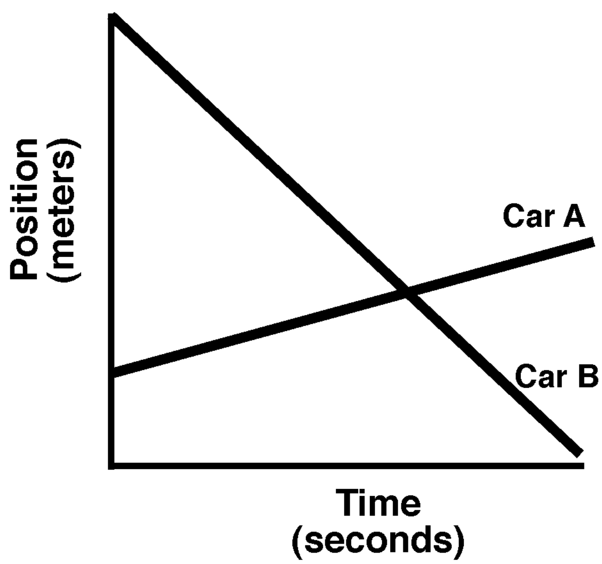
CONCEPT DEVELOPMENT

During the preceding exploration you recognized, from an object's position-time graph, when the object was moving and what direction it was moving in. You could also tell when one object was moving faster than another one.

During this development exercise you will calculate the speed of an object. You will also distinguish between what is meant by the instantaneous speed and the average speed of an object by using the object's position-time graph.

Engagement Question

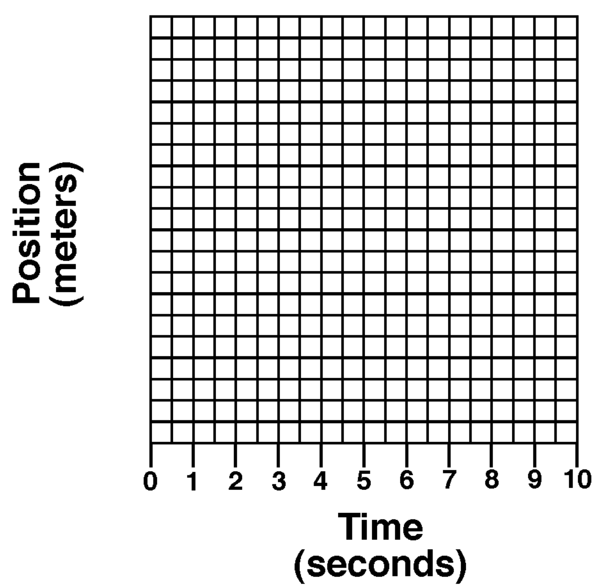
1. On the graph you see you see to the right decide which car is moving the fastest. How do you know? What direction is each car moving in? How do you know?



The Challenge

You will draw a position-time graph for an object that is initially at rest and then moves at a constant speed in one direction.

2. On the grid you see to the right sketch what you think the position-time graph will look like for an object that is initially at rest for 5 seconds and then moves away at a constant speed for 3 seconds.

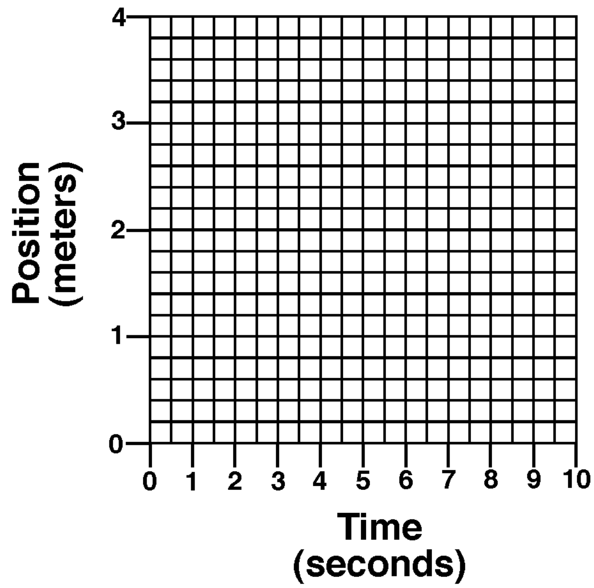


At each lab station you will find the following:
a computer with an interface, a motion detector, and a battery-powered car.

The Investigation

a. Place a car approximately 1/2 meter away from the motion detector.
b. Start the graphing program.
c. Let the program run for 5 seconds before you release the car. Release the car so that it moves directly away from the motion detector.
d. After 8 seconds stop the graphing program and stop the car.

3. On the grid provided to the right draw the shape of the graph that you have on your computer display.



4. Based on what you see on the graph explain how you can tell that the car was at rest for the first 5 seconds?

5. Based on what you see on the graph explain how you can tell that the car was moving for the following 3-second period?

6. Evaluate the following student statements about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

<u>Student A</u>
"A position-time graph can tell you whether or not an object is moving but it won't tell you exactly how fast the object is moving."

<u>Student B</u>
"Since we can tell that an object is moving from the slope of its position-time graph we should also be able to be able to tell the exact speed of the car from the value of its slope."

Check your work with your teacher. ☐

The Investigation (continued)

a. Pick two different points from the flat portion of your graph and record their coordinates in the data table that follows.
b. Pick two different points from the non-flat portion of your graph and record their coordinates in the data table that follows.
c. Fill out the table by performing the indicated operations.

Data

Graph Portions	Coordinate Pairs (x, y)		Rise (Δy) $y_2 - y_1$	Run (Δx) $x_2 - x_1$	$Slope = \frac{rise}{run} = \frac{\Delta y}{\Delta x}$
Flat	(x_1, y_1)				
	(x_2, y_2)				
Non-Flat	(x_1, y_1)				
	(x_2, y_2)				

8. What are the units that correspond to the y-coordinates on the vertical axis of your graph?

9. What are the units that correspond to the x-coordinates on the horizontal axis of your graph?

If you take the y-coordinate units and divide these by the x-coordinate units you get what is known as a derived unit. A **derived unit** is a combination of fundamental units.

10. What derived unit do you get when you divide the y-coordinate unit by the x-coordinate unit and what concept does the resulting derived unit correspond to?

11. What speed did your car have during the time that it was moving? Be sure to include the appropriate units.

12. What was the total distance attained by your car during the 8-second interval?

13. Divide the total distance that you have recorded in the preceding question by 8 seconds. Be sure to include the units in your calculations and label your answer appropriately.

Average speed = $\frac{\text{total distance}}{\text{8 seconds}}$ =

Average speed is defined as the total distance that an object moves divided by the total time that it took the object to move that distance.

14. During the 8-second graphing period, was there ever an instant in time during which your car was moving with the average speed that you calculated above? If so, when was this and how do you know?

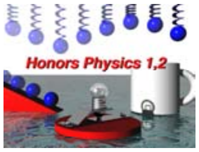
The speed that an object has at a particular instant in time is known as the **instantaneous speed**.

15. How can you tell the instantaneous speed of an automobile at any moment? What device in the automobile tells you instantaneous speed?

16. Evaluate the following student statement. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

"Since it took us 2 hours to drive the 120 miles to Los Angeles last weekend, our average speed was 60 mph. That's crazy! I know for a fact that we never went just 60 mph."

Check your work with your teacher. ☐



Kinematics
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CONCEPT REFINEMENT

Review

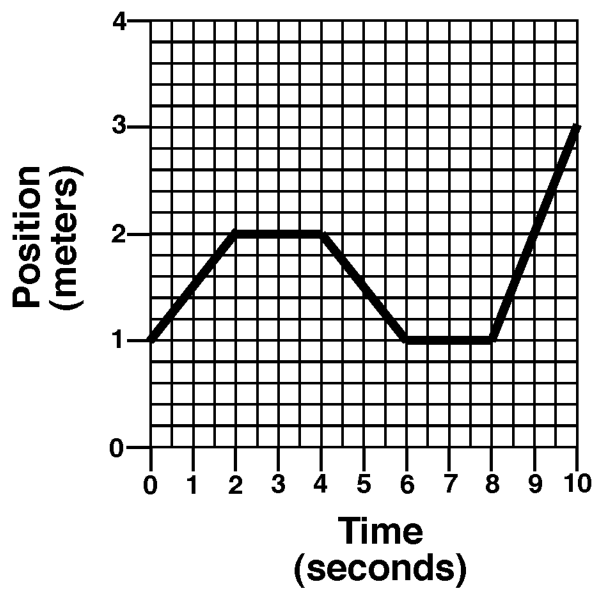
You have had the opportunity to produce position-time graphs for objects that were either at rest or were moving with a constant velocity.

Objects that are at rest will produce position-time graphs that consist of straight-horizontal lines (zero slope). Objects that are moving with a constant speed in a straight line will also produce position-time graphs that consist of straight lines. These lines, however, will have a non-zero slope. The direction of motion for an object can be determined by the positive or negative sign of the slope.

The velocity of an object, moving at a constant speed in a straight line, can be calculated by using the slope equation. You could select any two distinct points from a section of a graph that has a uniform slope in order to do this.

Average speed is defined as the total distance an object travels divided by the total amount of time that it took for the object to travel that distance.

The graph shown below represents the position of a rat running in straight lines on a floor for a period of 10 seconds.



Based on the graph answer the following questions.

1. **During which time period(s) is the rat not moving? ______________**

2. **During which time period(s) is the rat moving forward? ______________**

3. **During which time period(s) is the rat moving backwards? ______________**

4. **During which time period is the rat moving the fastest? ______________**

5. **What is the position of the rat at the end of;**

   a. **2 seconds?** ____________

   b. **4 seconds?** ____________

   c. **6 seconds?** ____________

   d. **10 seconds?** ____________

6. **What distance did the rat travel during the first;**

   a. **2 seconds?** ____________

   b. **4 seconds?** ____________

   c. **6 seconds?** ____________

   d. **10 seconds?** ____________

7. **What is the displacement of the rat during the first;**

   a. **2 seconds?** ____________

   b. **4 seconds?** ____________

   c. **6 seconds?** ____________

   d. **10 seconds?** ____________

8. **What instantaneous speed does the rat have at;**

   a. **1 second?** ____________

   b. **3 seconds?** ____________

   c. **5 seconds?** ____________

   d. **9 seconds?** ____________

9. **What instantaneous velocity does the rat have at;**

   a. **1 second?** ____________

   b. **3 seconds?** ____________

   c. **5 seconds?** ____________

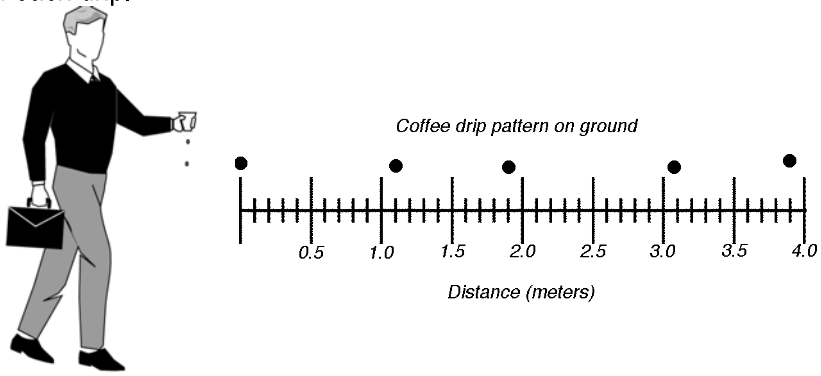
   d. **9 seconds?** ____________

10. **What is the average speed for this rat during the entire 10 seconds?**

$$\text{average speed} = \frac{\text{total distance}}{10\ \text{s}} =$$

Check your work with your teacher.

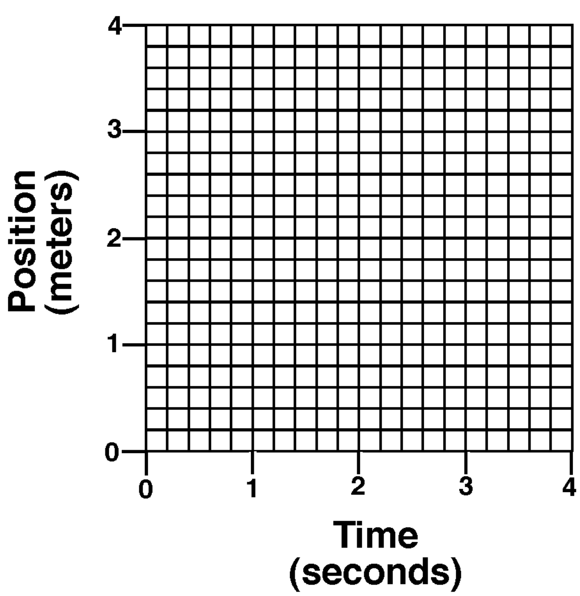
A teacher walks to class with a container full of coffee held in front of him. The coffee container has a leak that drips coffee at the rate of 1 drip per second. Below you see the pattern created by the dripping coffee as well as the location of each drip.



11. Fill out the table below for each of the points indicated by the pattern seen above.

Time (seconds)	Position (meters)
0	
1	
2	
3	
4	

12. Plot the points from your table on the position-time graph grid you see below.



On the graph above you need to draw the "best-fit" line that passes through the trend of the points. Do not just simply connect the dots.

13. Using a straight edge, you should draw the line that passes through the points in such a way that approximately half of your points are above the line and half below. This particular best-fit line should pass through the origin.

Pick two points off of your resulting best-fit line on the graph. Do not use data points. Ideally you should pick two widely-separated points.

14. Record their coordinate pairs below in the data table.

Point 1	(x_1, y_1)	
Point 2	(x_2, y_2)	

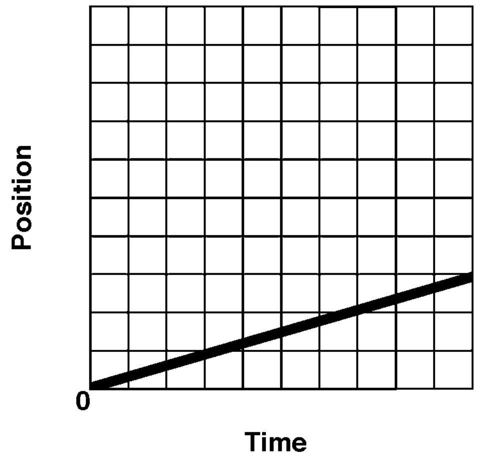
15. Calculate the slope of your resulting best-fit line. Be sure to carry through with the x and y units in your calculations and label your answer with the appropriate units.

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} =$$

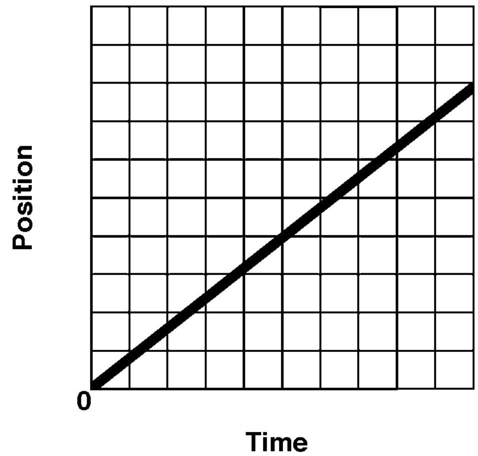
Check your work with your teacher.

The position-time graphs given below represent the motion of two different cars moving with uniform speed.

Car A



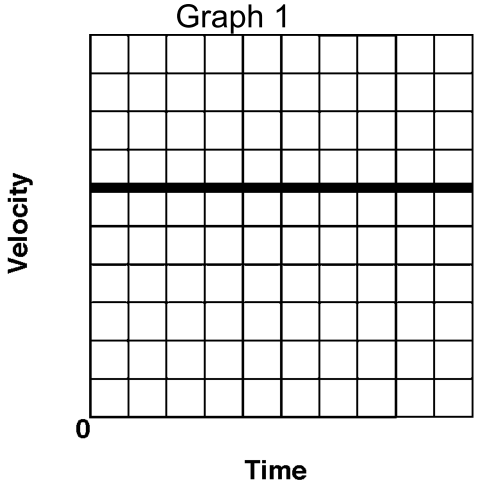
Car B



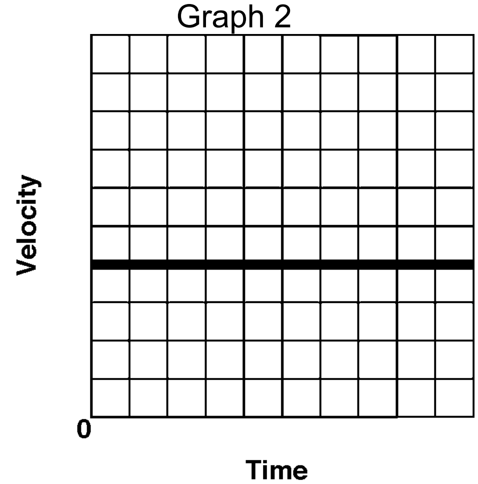
The two velocity-time graphs seen below represent the same motion by the same cars during the same time period.

16. Match up each position-time graph seen above with each of the velocity-time graphs seen below by labeling graph 1 and 2 as either car A or B.

Graph 1



Graph 2



17. Explain why you matched up the graphs as you did.

Check your work with your teacher