Kinematics
Uniform Acceleration

CONCEPT EXPLORATION

We have defined velocity as being the rate of change of position. **Acceleration** is the rate of change of velocity. The accelerations we will explore will be constant. We use the term "**uniform**" to describe a rate that does not change. We therefore refer to an acceleration that is unchanging or constant as **uniform acceleration**.

Acceleration can be a difficult concept to master. Since it is the rate at which the velocity (another rate) is changing, it can be considered to be a rate of a rate. This aspect of acceleration not only makes the concept difficult to understand but it also makes the units of measure somewhat complex.

Engagement Question

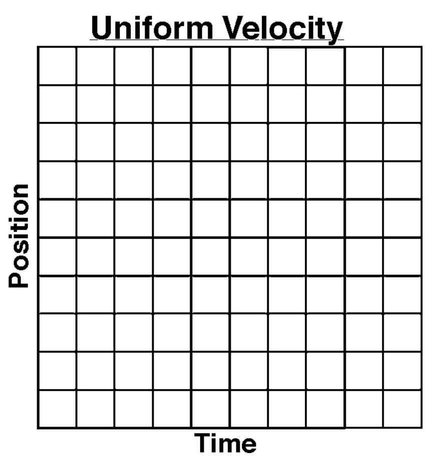
1. What is the official name for the foot-pedal that you would push on to make an automobile go faster?

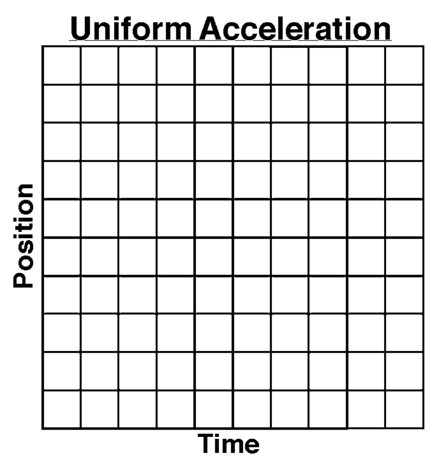
The Challenge

You will draw a position-time graph for an object that starts from rest and speeds up while going forward.

Your Ideas about the Challenge

2. On the grids provided below sketch what you think the position-time graphs will look like for one object that is moving with a uniform velocity in the forward direction and the other object is moving with uniform acceleration so that it is speeding up in the forward direction.



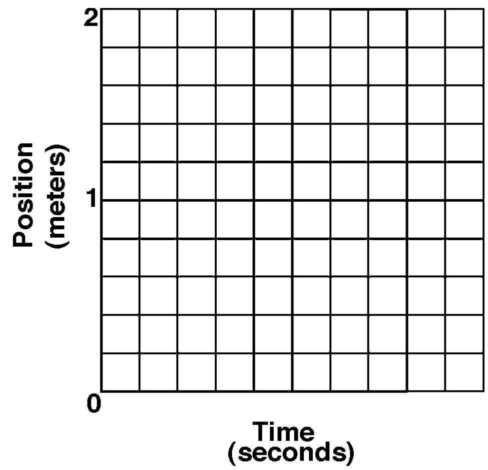


At each lab station you will find the following:
a computer with an interface, a ramp, a ball bearing, a lab cart and a motion detector.

The Investigation

a. Make sure that your ramp is lying level on the table with no incline.
b. Place the motion detector at one end of the ramp.
c. Place the lab cart approximately 0.5 meter away from the motion detector.
d. After your lab partner starts the graphing program roll the lab cart in a direction directly away from the motion detector so that it maintains a uniform velocity.

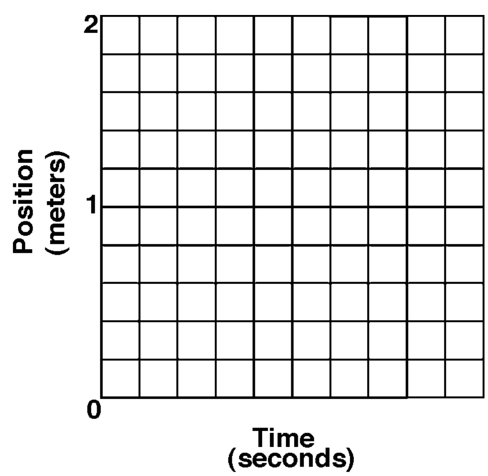
3. Draw the resulting position-time graph on the grid provided below. Be sure to confine your drawing to the portion of the resulting graph that corresponds to the time that the ball was rolling with a uniform velocity.



The Investigation (continued)

a. Elevate your ramp at one end by placing several books below one end of the ramp.
b. Place the motion detector at the top of the ramp facing downwards.
c. Place the ball bearing on the ramp approximately 0.5 meter below the motion detector.
d. After your lab partner has started the motion detector release the ball bearing from rest so that it rolls down the ramp away from the motion detector.
e. Stop the ball and the graphing program when the ball bearing reaches the bottom of the ramp.

4. Draw the resulting position-time graph on the grid provided below. Be sure to confine your drawing to the portion of the resulting graph that corresponds to the time that the ball was rolling down the ramp.



5. How does the resulting slope on the position-time graph for the ball bearing rolling down the ramp compare to that of the lab cart that was rolling on the level ramp? Are they both straight lines?

6. How can you explain the kind of slope that you received on the position-time graph for the ball rolling down the ramp? Hint: What does slope on a position-time graph indicate? What is happening to the steepness of the graph as the ball rolled down the ramp?

7. 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
"A straight line has a constant slope. Since slope on a position-time graph indicates velocity, a straight line indicates a constant velocity. A curved line has a changing slope. This would indicate the ball had a changing velocity. Changing velocity is acceleration."

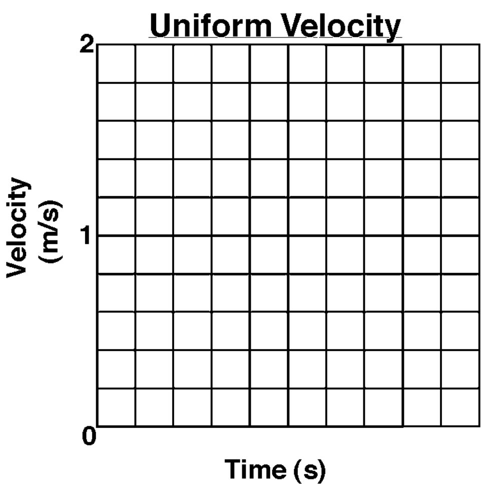
Student B
"The position-time graph for the ball rolling down the ramp was curved because the ball was not rolling on a flat surface."

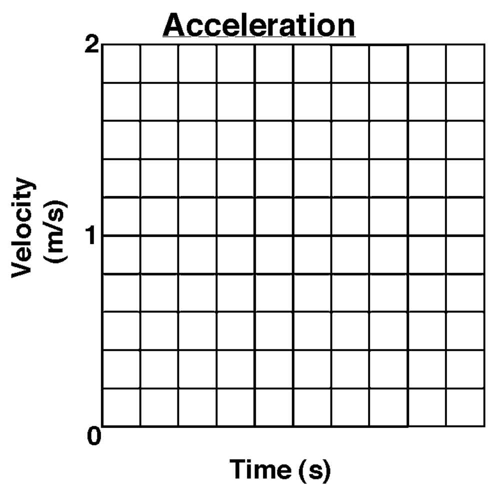
Check your work with your teacher.

The Investigation (continued)

Repeat both of the previous two investigations, this time with a velocity-time graph on the computer display. Your teacher can assist you in placing a velocity-time graph on your computer display.

8. Draw both of the resulting velocity-time graphs on the two grids provided below. Be sure to confine your drawings to the time when the ball was moving away from the motion detector with uniform velocity and when it was accelerating down the ramp.



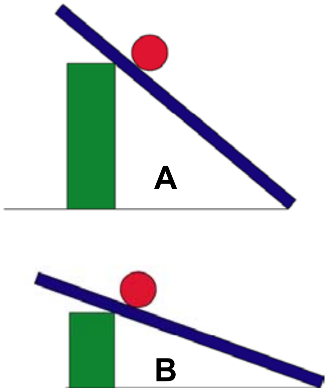


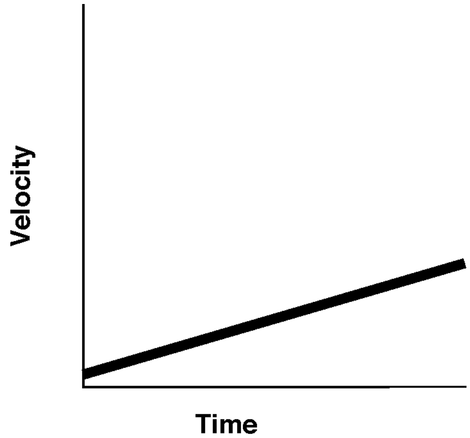
9. Describe how the two resulting velocity-time graphs compare. Are they both straight lines? How would you describe the difference between the two resulting slopes?

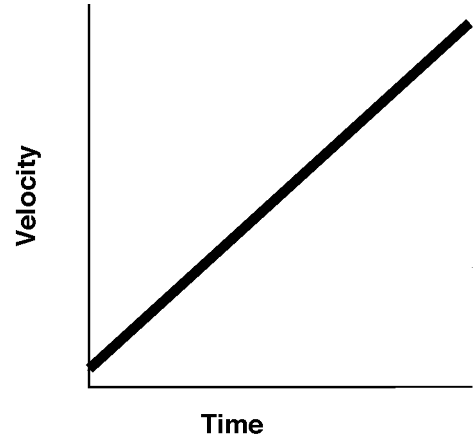
10. Why do you think the slopes for the two graphs were different? What do you think is the meaning of slope on a velocity-time graph?

Suppose you rolled the same ball down the two different ramps you see pictured below. This action produced the two velocity-time graphs that you also see below.

13. Label each graph with the ramp that you think produced that particular graph.







12. Explain why you made the selection that you did when you paired each ramp and ball with its corresponding velocity-time graph.

13. 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>
"The velocity-time graphs for the lab cart rolling on the flat ramp and the ball bearing rolling down the tilted ramp were both straight lines. This is because they were following a straight-line path in both cases."

<u>Student B</u>
"Slope on a position-time graph gave you velocity information. Velocity is the rate of change of position. Slope on a velocity-time graph must give you information about the rate of change of velocity."

Check your work with your teacher.

A special acceleration that you will deal with is the acceleration of gravity. When we refer to the **acceleration of gravity** we are usually referring to the rate of acceleration that a body would experience as it fell close to the earth's surface.

The Challenge
You will determine the relationship between the mass of an object and the acceleration of gravity.

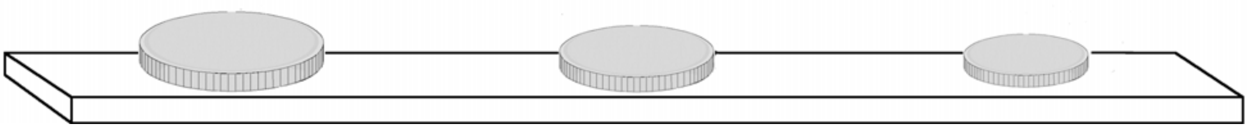
Your Ideas about the Challenge

14. An 8-lb shotput and a baseball are released from rest from the same height and at the same time. Which object will hit the ground first? Why do you think that this will happen?

At each lab station you will find the following:
a meter stick, a motion detector, several masses of various size, and several coffee filters.

The Investigation (continued)

a. Place the three different masses, of various size, on top of the meter stick lying on the counter top.
b. Carefully lift the meter stick off of the counter top so that it remains horizontal.



c. Hold it out from your body at about chest level.
d. On the count of three tilt the meter stick so that all three masses are released from rest and begin to drop to the floor at the same time and from the same height.
e. Repeat this process several times, taking note each time of which mass, if any, hit the floor first.

15. Did one mass consistently hit the floor before the others? If so, was there a significant time difference between the moments at which the different masses hit the floor?

16. Does the mass of an object determine the rate at which it falls under the influence of gravity? How do you know?

The Investigation (continued)

a. Crumple up one of the coffee filters into a tiny ball.
b. Hold the crumpled coffee filter along with an uncrumpled coffee filter out from your body at the same height from the floor.
c. Release these from the same height at the same time so that they fall to the floor.

17. Did the two coffee filters have significantly different masses?

18. Did the two coffee filters hit the floor at the same time? If not, how do you explain the different rates of fall for the two filters?

19. Compared to the way in which the three different masses fell, what is different about the mass distribution of the two coffee filters that allows them to fall at two different rates?

20. 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.

"All of the masses were heavier than the uncrumpled coffee filter. The crumpled coffee filter was also heavier and this is why all of these objects fell faster than the uncrumpled filter."

Check your work with your teacher.

Kinematics
Uniform Acceleration

CONCEPT DEVELOPMENT

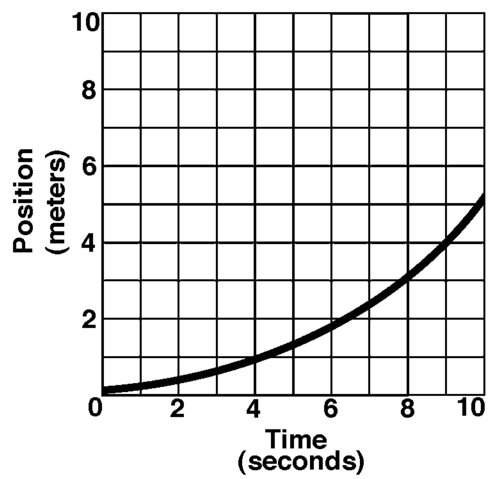
From the exploration activity you determined that position-time graphs for accelerating objects consisted of "curved" lines. Slope on position-time graphs indicates both the speed and direction (velocity) of a moving object. A curve is a line with a changing slope. A curved line then would indicate a changing velocity. Since **acceleration** is the rate of change of velocity, a curved line on a position-time graph would indicate that acceleration is taking place.

In this development activity you will investigate the way that the amount of distance covered, during equal and consecutive time periods, changes for an accelerating object. You will also produce position-time graphs for accelerating objects as well as the corresponding velocity-time graphs for the same motion. Just as you discovered that slope has meaning for position-time graphs you will find that this is also true for the slope on a velocity-time graph.

Finally, you will calculate an experimental value for the acceleration of gravity close to the earth's surface.

Engagement Question

1. Describe what you would be doing in your car if the position-time graph seen to the right represented your motion for 10 seconds. What kind of motion would you experience?

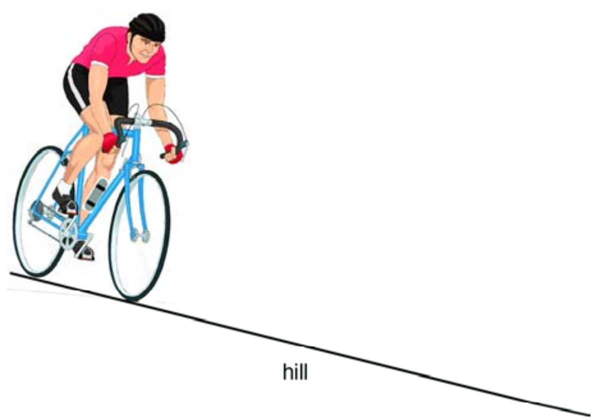


The Challenge

You will indicate the positions, at 1-second intervals, for an object undergoing uniform acceleration.

A cyclist starts coasting down a hill that has a constant slope. The cyclist's water bottle has sprung a leak so that water drips out at a rate of one drop per second.

2. On the hill shown to the right draw the positions of the drops of water as they might appear due to the motion of the cyclist.



At each lab station you will find the following:
A computer with an interface, a ramp, a ball bearing, a motion detector, some masking tape, and a stopwatch.

The Investigation

a. Place books or other objects under your ramp in such a way that it will take at least 4 seconds for your ball bearing to roll down the ramp.

b. Mark a starting position (with masking tape) at the top of your ramp.

c. Place the ball bearing at the starting position.

d. One student should start the stopwatch and release the ball bearing from rest at the starting position.

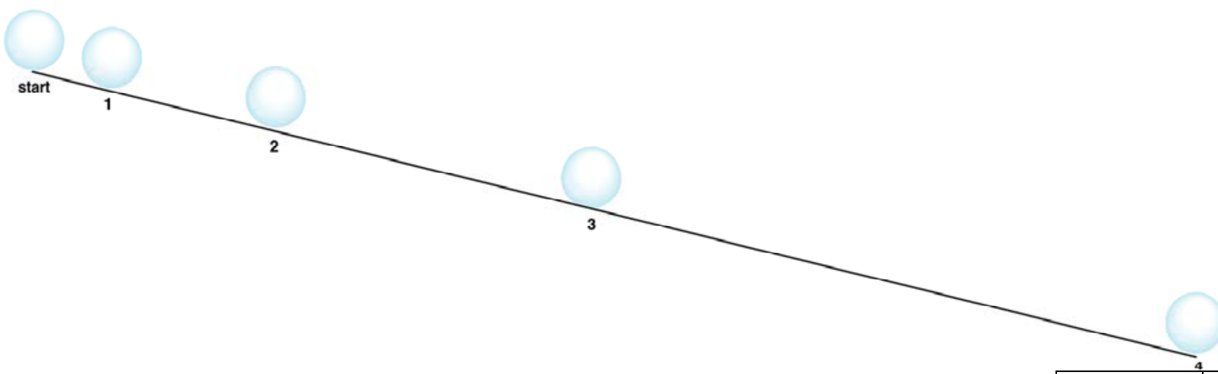
e. The student with the stopwatch should call out the seconds. At the end of each second the other members of the lab group should note the position of the ball bearing as it accelerates down the ramp.

f. Place a piece of masking tape at the positions that the ball bearing reaches at the end of each second.

g. Be sure to place a mark on the tape at what appears to be the approximate position of the ball.

h. You will need to roll the ball down the ramp numerous times and reposition the masking tape several times until you feel that the position of the ball is correct at 1-second intervals.

i. Measure the distance (to the nearest tenth of a centimeter) between the starting position and each of the 1-second positions and record these distances in the data table that follows.



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

4. Approximately how many times bigger is the 2-second position compared to the 1-second position. Is it twice as big? . . . three times as big?

5. Approximately how many times bigger is the 3-second position compared to the 1-second position?

6. Approximately how many times bigger is the 4-second position compared to the 1-second position?

7. 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.

"Because the ball was speeding up it was covering a greater amount of distance during each second that it was moving. The distance that it traveled in the first two seconds was almost 4 times greater than the first second alone."

Check your work with your teacher.

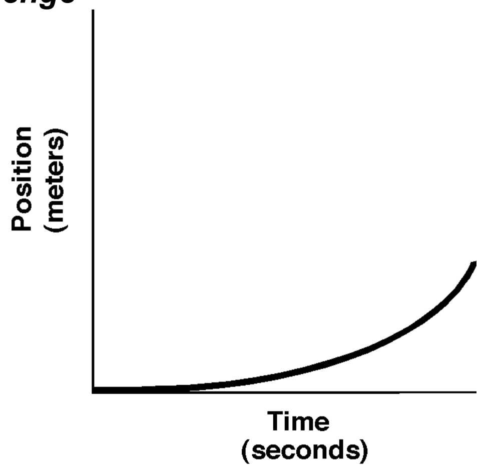
The Challenge (continued)

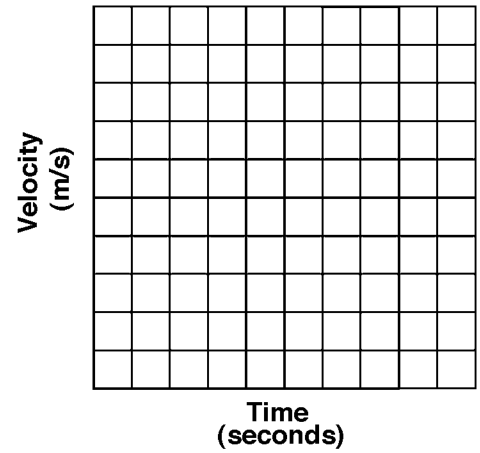
You will draw the velocity-time graph that corresponds to a particular position-time graph.

Your Ideas about the Challenge

8. Given the graph you see to the right draw the velocity time graph, on the velocity-time grid provided, that you think would represent the same motion during the same time interval.

Assume that you have *uniform* acceleration.





Your instructor will help you place both a position-time graph and a velocity-time graph on your computer display.

The Investigation (continued)

a. Place the motion detector at the top of the ramp facing downwards.

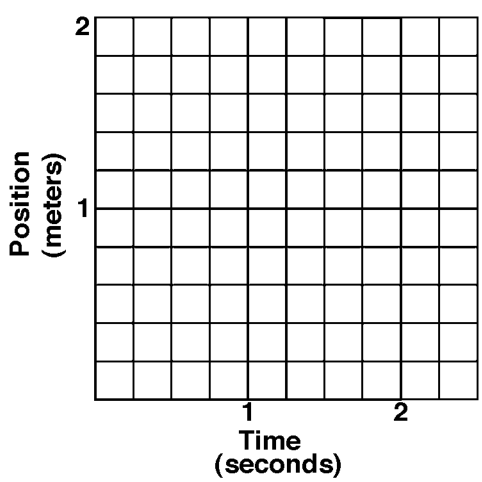
b. Place the ball bearing approximately 0.5 meter below the motion detector.

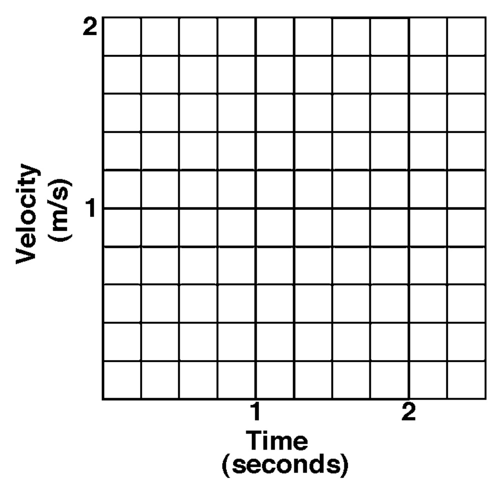
c. Your lab partner should start the graphing program.

d. Release the ball bearing from rest.

e. Stop the graphing program when the ball reaches the bottom of the ramp.

9. Draw both the position-time graph and the velocity-time graph, you see on the computer display, on the respective grids provided below. Try to confine your drawings to the times on the graphs that corresponded to the time that the ball was actually rolling down the ramp.





10. Describe the general shape of the resulting velocity-time graph. Is the resulting velocity-time graph a fairly straight line? Does the resulting line have a positive or a negative slope?

As indicated earlier in this development activity the slope of a velocity-time graph has significance.

11. Select two data points off of the sloped straight-line portion of your resulting velocity-time graph and record their coordinates in the data table that follows. Perform the calculations for slope as indicated by the table.

Coordinate Pairs (x, y)		Rise (Δy) $y_2 - y_1$	Run (Δx) $x_2 - x_1$	Slope $= \frac{\text{Rise}}{\text{Run}} = \frac{\Delta y}{\Delta x}$
(x_1, y_1)				
(x_2, y_2)				

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

13. 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 $\frac{m/s}{s}$. Velocity units divided by time units give you derived units that express the rate at which the velocity is changing (a rate of a rate).

14. What motion concept must this derived unit ($\frac{m/s}{s}$) correspond to?

15. What must have been the acceleration of your ball bearing as it rolled down the ramp? Be sure to include the appropriate units.

16. 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>
"The slope on a position-time graph corresponded to the velocity of the object. Velocity is the rate of change of position. Therefore the slope on a velocity-time graph should correspond to the rate of change of velocity, which is the acceleration."

<u>Student B</u>
"I think that the steepness of the slope on a velocity time graph shows how fast the velocity is changing. If the velocity is changing then there must be an acceleration."

Check your work with your teacher.

The Challenge (continued)
You will calculate an experimental value for the acceleration of gravity.

Your Ideas about the Challenge

17. What is the direction of gravitational acceleration? Would this direction be the same if you were in Australia?

At each lab station you will find the following:
A computer with an interface, a photogate, and a picket fence device.

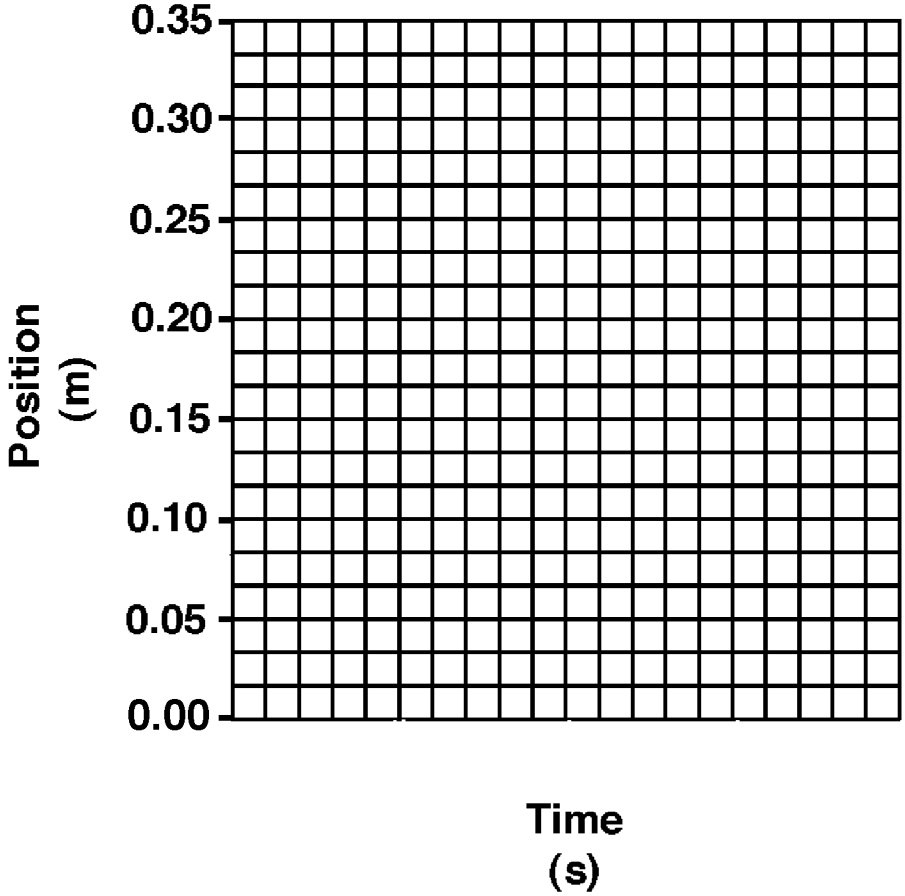
The Investigation (continued)
a. Place the photogate so that it extends over the edge of the counter.
b. Hold the vertically-oriented picket fence by the top edge so that the bottom edge aligns with the top of the photogate.
c. After you have started the graphing program, drop the picket fence so that it starts from rest and falls cleanly through the photogate.
d. One student should be prepared to catch the picket fence after it has completely passed through the photogate.
e. Place a header at the top of your tables.
f. Print out a copy of your tables.
g. Transfer the data from your printed copy of the tables into the tables provided in the data section that follows.

Data Table s

Time (s)	Position (m)

Time (s)	Velocity (m/s)

18. On the position-time grid provided below plot the points from your position-time table. You may have to adjust the starting point for the time axis. Check with your teacher if you have any questions.

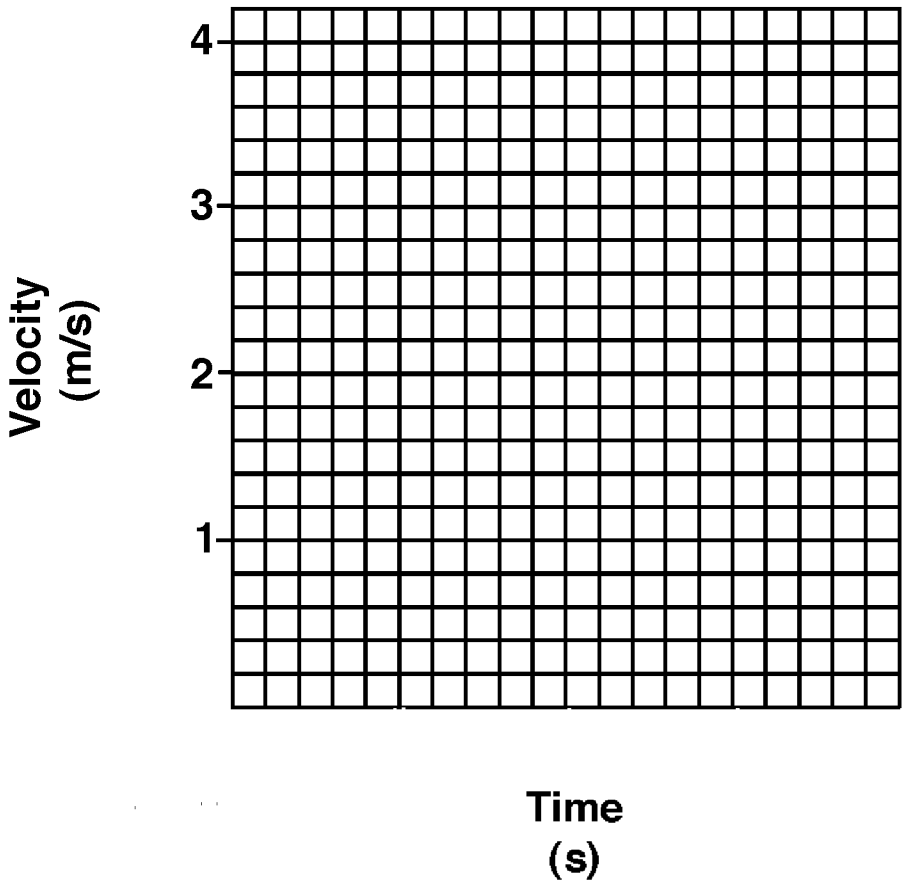


19. Draw a line through the points on your position-time graph that follows the trend in the data.

20. Why does the position-time graph result in a curve for your falling picket fence?

21. Does the slope of your position-time graph increase or decrease? Explain why this occurs on your graph.

22. On the velocity-time grid that you see below plot the points from your velocity-time table. Once again you may have to adjust the starting point for the time axis. Check with your teacher if you have any questions.



23. Using a straight edge draw a best-fit line through the data points on your velocity-time graph. The line should pass through the "trend" of the points.

24. Pick two points from the resulting best-fit line (do not use data points) and record their coordinates in the table that follows. Proceed to fill out the table and calculate the slope of your best-fit line. Label your rise value and your run value with the appropriate units. Be sure to label your final value for your slope with the appropriate units.

Coordinate Pairs (x, y)		**Rise (Δy)** $y_2 - y_1$	**Run (Δx)** $x_2 - x_1$	Slope $= \frac{\text{Rise}}{\text{Run}} = \frac{\Delta y}{\Delta x}$
(x_1, y_1)				
(x_2, y_2)				

25. What does the slope correspond to on your velocity-time graph?

Check your work with your teacher.

Kinematics
Uniform Acceleration

CONCEPT REFINEMENT

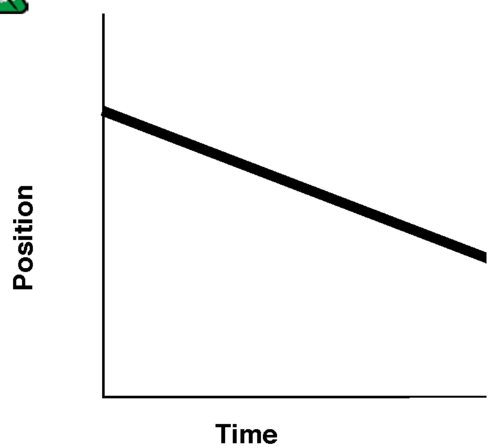
Review

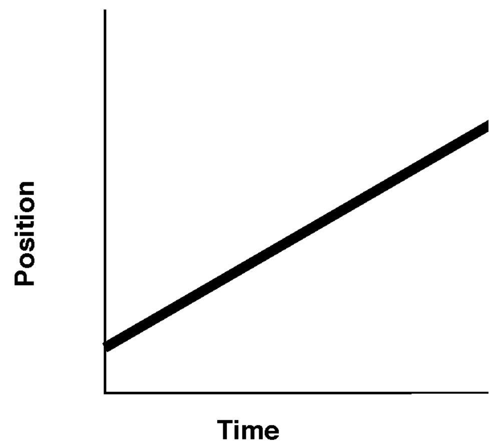
You have now had several laboratory experiences involving both position-time graphs and velocity-time graphs for objects that were undergoing uniform acceleration. This homework/worksheet will review and refine the ideas addressed in the previous activities.

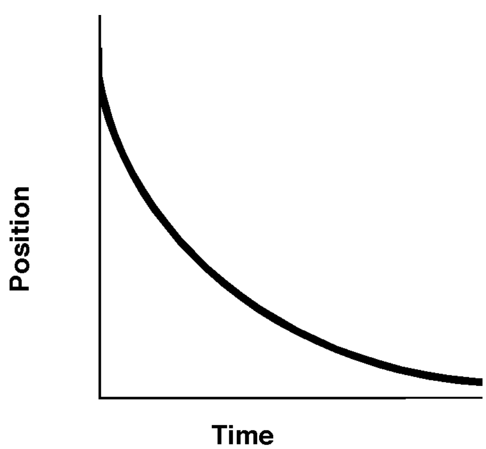
Position-time graphs for accelerating objects are curved while the velocity-time graphs for objects with uniform acceleration consist of straight lines with a non-zero slope. The slope on the velocity-time graph gave you the magnitude of the acceleration for the objects.

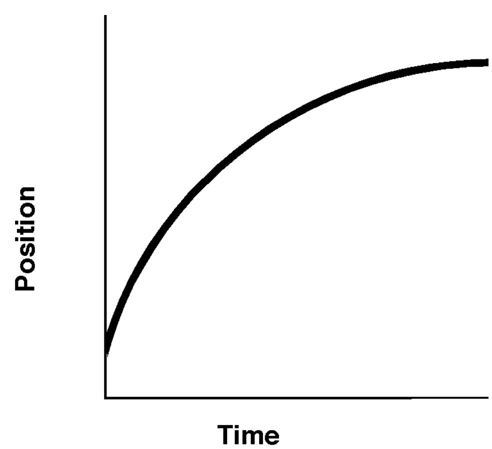
1. How can you tell the direction an object is moving from its position-time graph?

2. Label the graphs seen below to indicate which ones show an object moving forward and which ones show an object moving backwards.



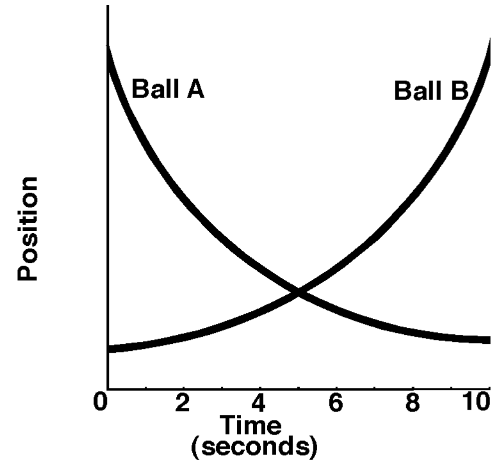






3. How can you tell how fast an object is moving from its position-time graph?

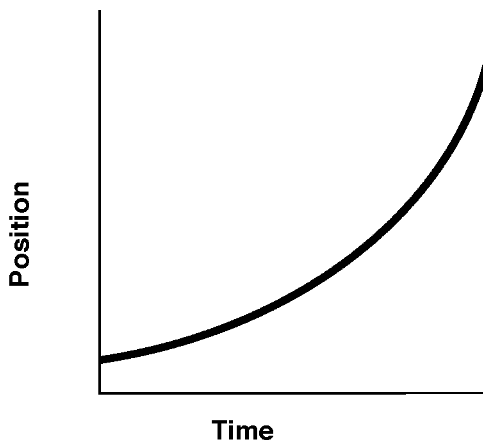
4. **On the graph to the right indicate which ball is speeding up and which ball is slowing down.**

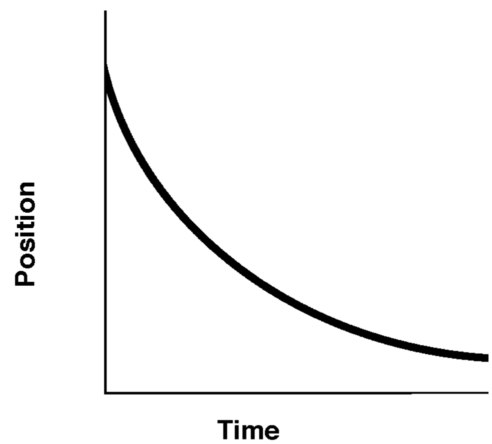


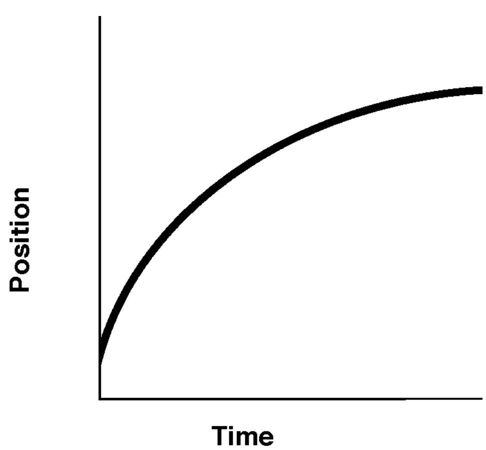
5. **Label each graph that follows to indicate whether the motion being shown in the graph represents the object;**

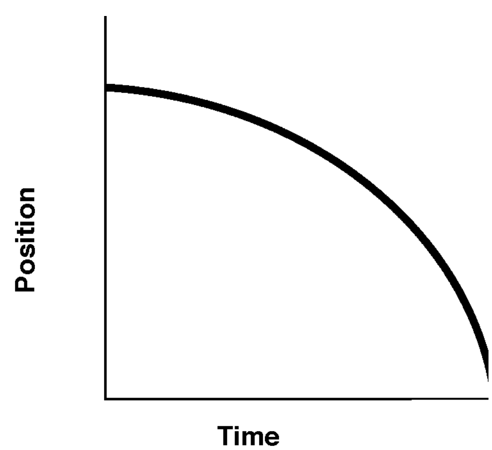
a. **going forwards or backwards**

b. **speeding up or slowing down.**









6. **Indicate whether each of the following descriptions for the motion of a car represents *positive* acceleration or *negative* acceleration. The car is going;**

a. **forward and speeding up.** ____________

b. **forward and slowing down.** ____________

c. **backward and speeding up.** ____________

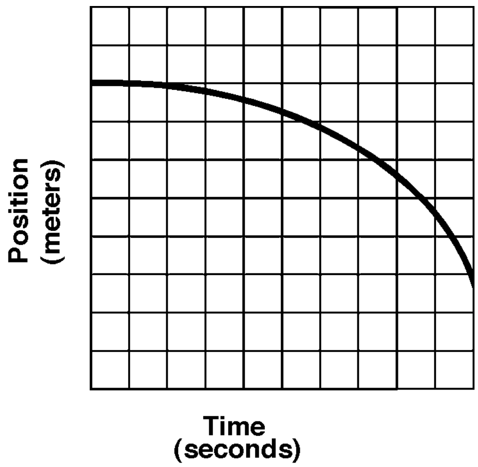
d. **backward and slowing down.** ____________

7. **How could you describe the way the graphs curve for the two graphs that show positive acceleration? Do the graphs curve up or down?**

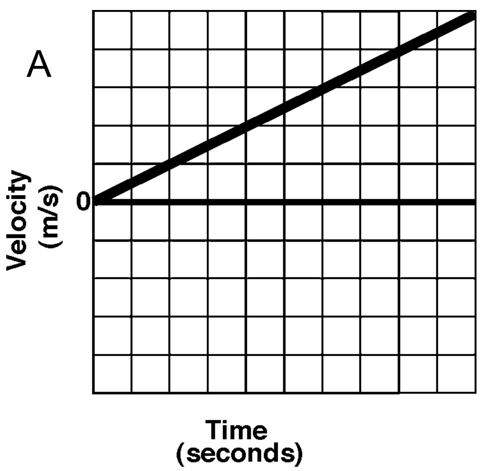
8. **How could you describe the way the graphs curve for the two graphs that show negative acceleration? Do the graphs curve up or down?**

Check your work with your teacher.

9. **Which of the following velocity-time graphs correspond to the given position-time graph?**



A



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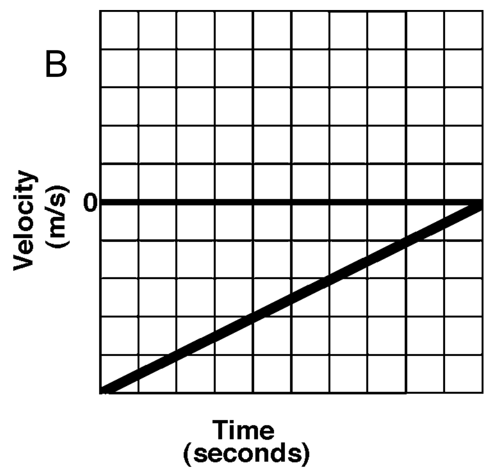

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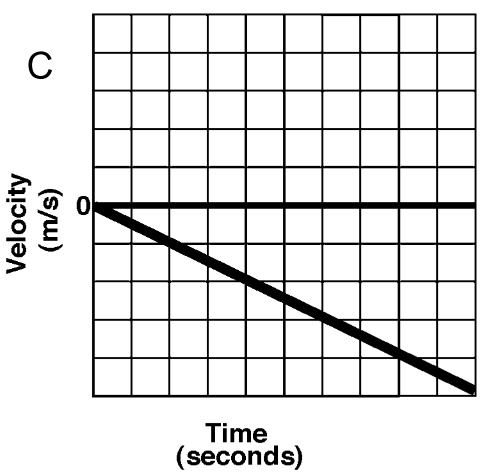

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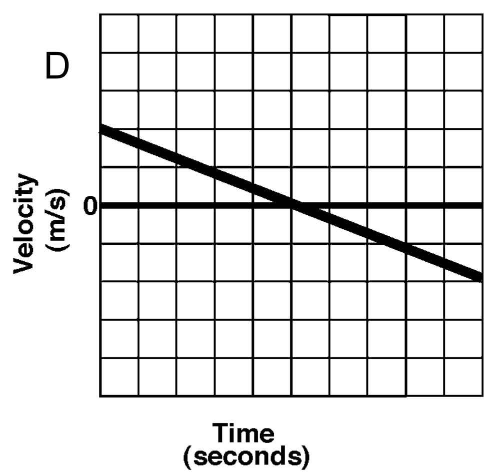
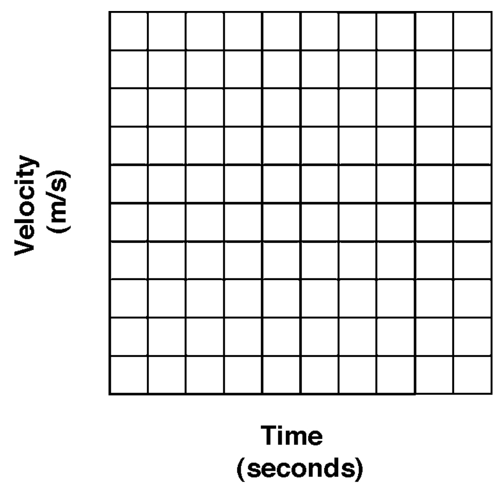


The accepted value for the rate of gravitational acceleration close to the surface of the earth is approximately $9.8\ \frac{\text{m}}{\text{s}^2}$. For approximation purposes you can round this value off to $10\ \frac{\text{m}}{\text{s}^2}$. Even though gravitational acceleration depends on location we generally treat the rate of gravitational acceleration, close to the surface of the earth, as a constant. The symbol used for this value is "g", not to be confused with "g" for grams.

The data table shown below represents the velocity of a rock, that was released from rest, from the top of a cliff on the surface of Mars.

Time (seconds)	Velocity (m/s)
0	0
1	3.6
2	7.5
3	11.0
4	14.9
5	18.4

10. Plot the points from the data table on the velocity-time grid provided to the right. Be sure to label the axes with regular position and time intervals that will "spread out" the data points as much as possible.



11. Draw the best-fit line through the trend of the points using a straight edge.

12. Calculate the slope of the best-fit line by selecting two points on your best fit line and use the slope equation. Be sure to carry through all of your units and label the answer appropriately.

13. What is the significance of the slope that you calculate for your velocity-time graph?

Check your work with your teacher.

For the following problems use the approximate value of $9.8\ \frac{\text{m}}{\text{s}^2}$ for the rate of gravitational acceleration (g).

A bowling ball is dropped off of a high cliff on the surface of the earth.

14. Assuming that the bowling ball is released from rest calculate the speed of the bowling ball at the end of:

a. 0 seconds

b. 1 second

c. 2 seconds

d. 5 seconds

15. Calculate the position of the bowling ball at the end of:

a. 0 seconds

b. 1 second

c. 2 seconds

d. 5 seconds

16. What is the acceleration of the bowling ball at the end of:

a. 0 seconds

b. 1 second

c. 2 seconds

d. 5 seconds

Check your work with your teacher. ☐