Name_____________________________ Date_________________

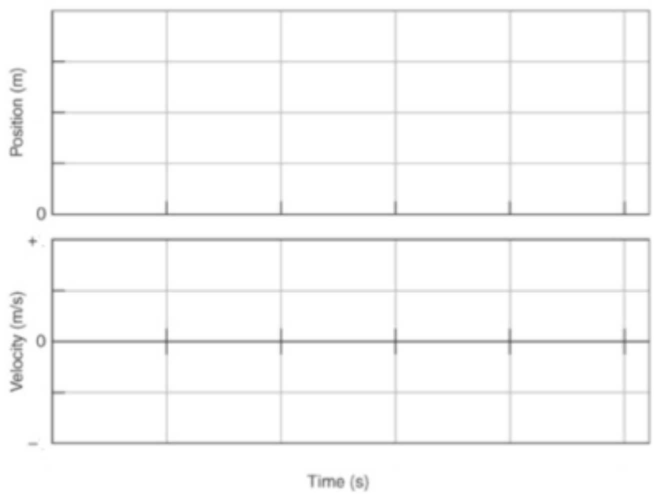
PRE-LAB PREPARATION SHEET FOR LAB 8: TWO-DIMENSIONAL MOTION (PROJECTILE MOTION)

(Due at the beginning of Lab 8)

Directions:

Read over Lab 4 and then answer the following questions about the procedures.

1. Sketch your Prediction 1-1 on the axes below.



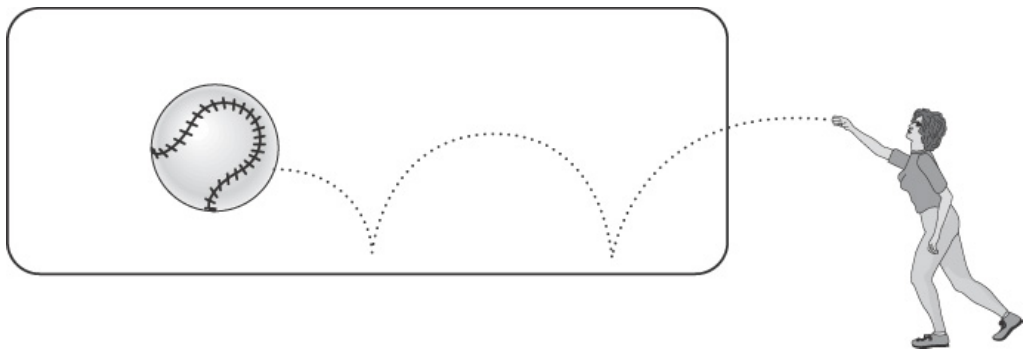
2. How will you measure the motion of the IOLab along the inclined ramp?

3. How will you measure the motion of the tennis ball that is tossed over the books in the video?

4. How will you determine the kinematic equations for the vertical motion of the tennis ball?

Name___________________ Date ______________ Partners_____________________

LAB 8: TWO-DIMENSIONAL MOTION (PROJECTILE MOTION)



The essential fact is that all the pictures which science now draws of nature . . . are mathematical pictures.—Sir James Jeans

OBJECTIVES

- To explore the type of motion that results when an object falls close to the Earth's surface.
- To review how two-dimensional vector quantities such as velocities and accelerations can be represented by components that can be treated independently.
- To understand the experimental and theoretical basis for describing projectile motion as the superposition of two independent motions: (1) that of a body falling in the vertical direction under the influence of the nearly constant gravitational force, and (2) that of a body moving in the horizontal direction with no applied forces.

OVERVIEW

So far we have dealt separately with motion with a constant velocity, and motion with a constant acceleration. The focus of this lab is to describe the motion close to the surface of the Earth that occurs when an object is allowed to move in both the vertical and horizontal directions. Examples are the motion of a baseball or tennis ball after being tossed or hit. This type of motion is commonly called *projectile motion.* To understand this motion, it is helpful to review motion with a constant velocity and motion with a constant acceleration separately and then consider how they might be combined.

The lab begins with a review of the classic *kinematic equations* that describe the relationships between instantaneous position, velocity, and acceleration of objects that move in one dimension. In some cases objects move with a constant velocity (zero acceleration). In others, such as the motion of an object tossed straight upward and pulled by the constant gravitational force, the motion is with a constant acceleration. You have already examined examples of these types of one-dimensional motion in Lab 1.

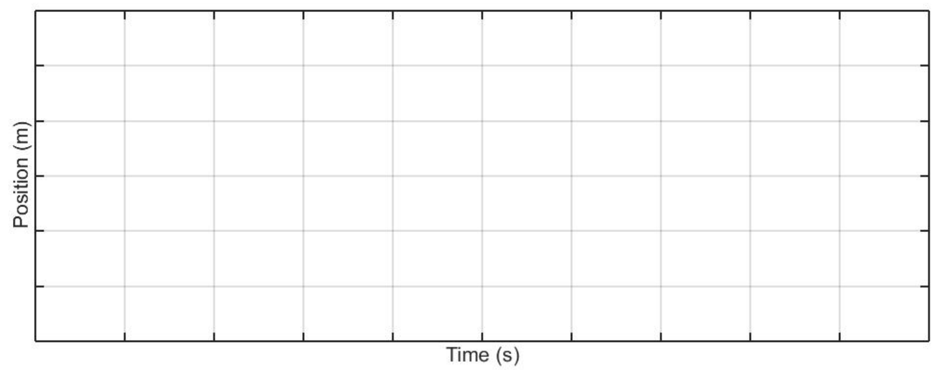
In this lab you will focus on the simultaneous vertical and horizontal motions of objects with a horizontal component of velocity while acted on by the downward gravitational force of attraction of the Earth in the vertical direction.

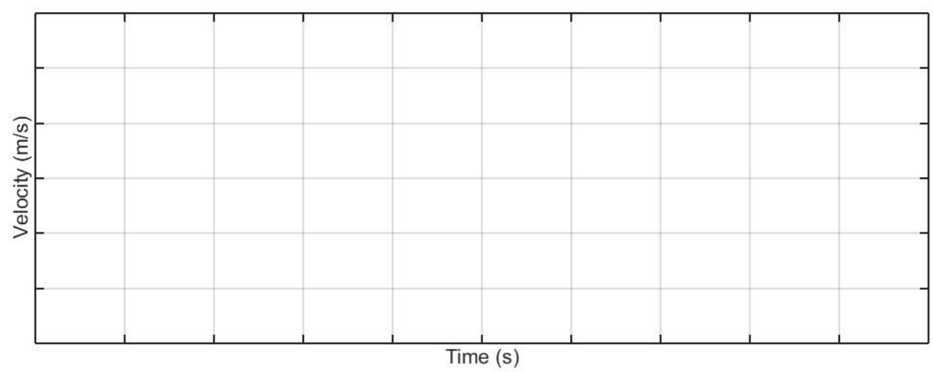
INVESTIGATION 1: REVIEW OF ONE-DIMENSIONAL MOTION

You'll begin by reviewing the one-dimensional motions of a cart.

Prediction 1-1: Suppose that you push the IOLab along a horizontal table at a constant velocity and measure its position and velocity as functions of time using the **Wheel** sensor. Use the PREDICTION axes below to sketch your predictions of the IOLab position and velocity as functions of time for this constant velocity motion.

PREDICTION





To test your predictions, you will need

- IOLab
- smooth, horizontal surface at least 0.5 m long (e.g., tabletop)
- computer and IOLab software

Activity 1-1: Motion of the IOLab Rolling Horizontally with a Constant Velocity

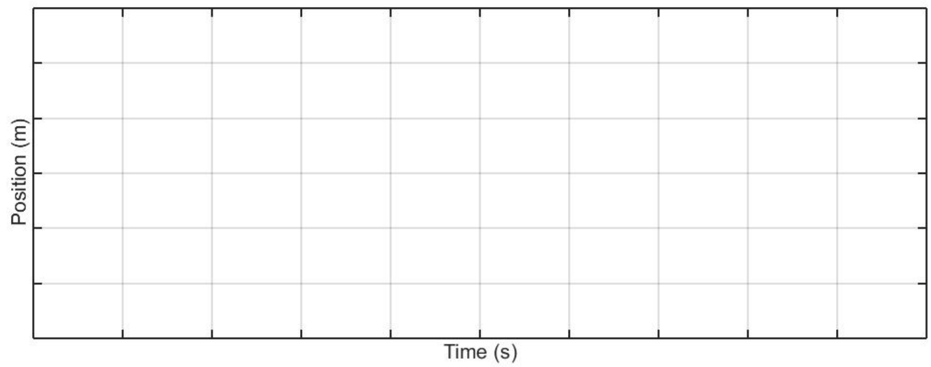
1. Set up the IOLab to collect data with the **Wheel** for **position** and **velocity**.

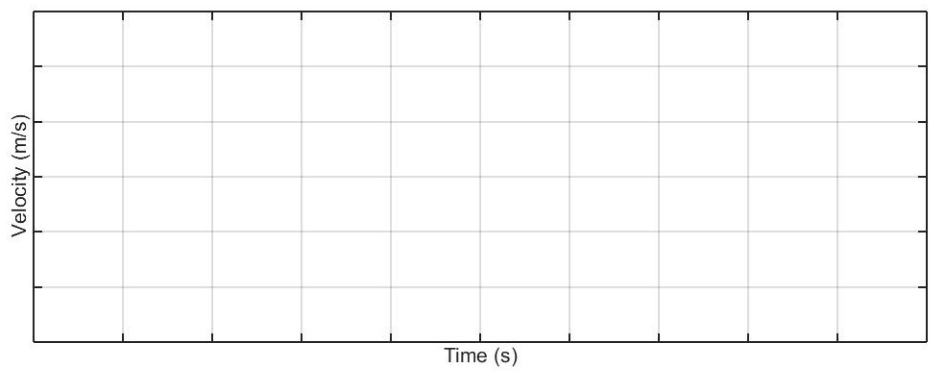
2. Click the **Reverse y-axis box**. (Remember that this just sets the +y direction as positive.)

3. Collect graphs for the motion of the IOLab along the tabletop as you push it with a constant velocity in the positive y direction (as indicated by the axes on the IOLab).

4. Keep a copy of your graphs (print or save) and sketch your results on the RESULTS axes that follow. (Be sure that the graphs are labeled clearly with the correct times.)

RESULTS



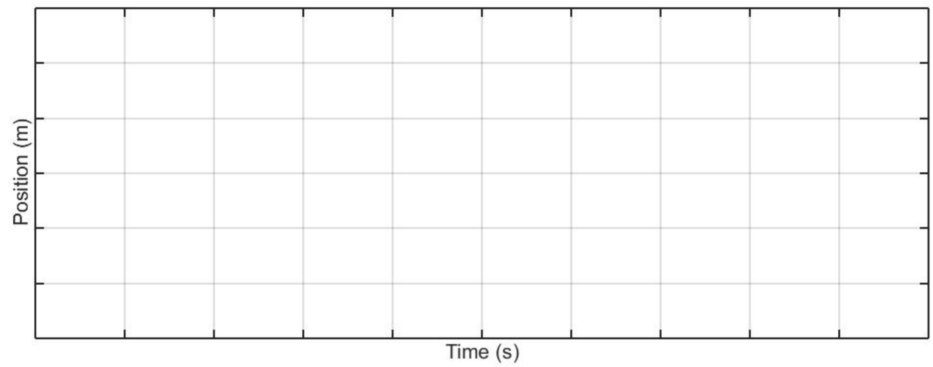


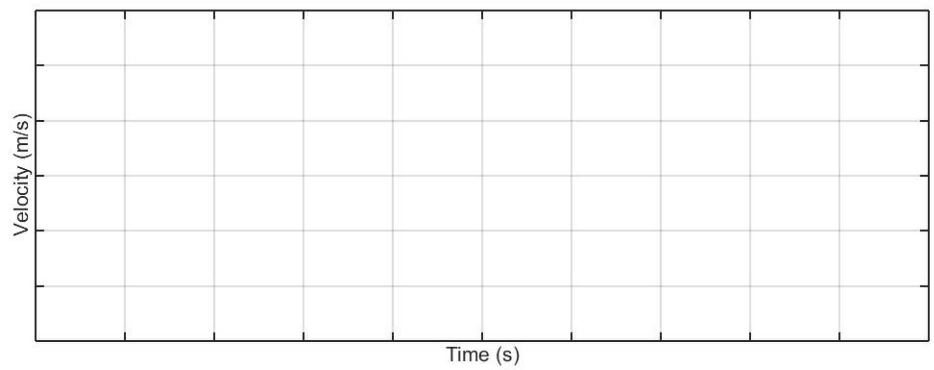
Question 1-1: Describe the shapes of your graphs. Did they agree with your predictions?

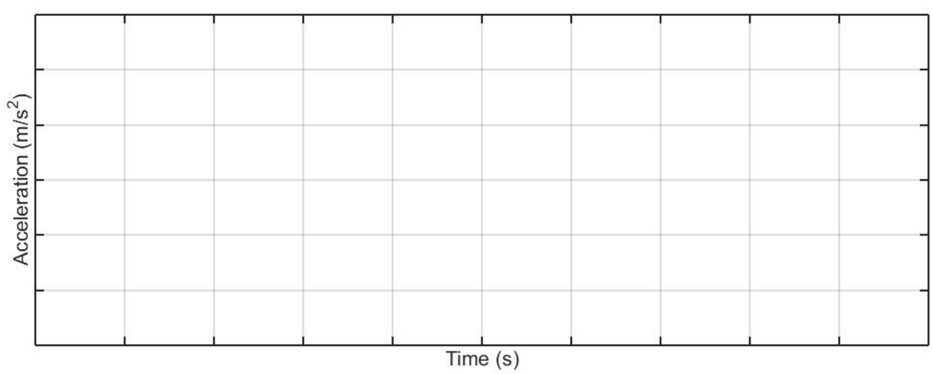
Question 1-2: For this motion with a constant velocity, what would the graph of acceleration vs. time look like? Explain.

Prediction 1-2: Now suppose you give the IOLab a push up an inclined ramp, allow it to move up in the positive y direction, reach its highest point, reverse direction and come back down. You stop it with your hand when it returns to its original position. Use the PREDICTION axes below to sketch your predictions for the position, velocity, and acceleration of the IOLab from the moment it leaves your hand until just before you stop it.

PREDICTION







To test your predictions, you will need

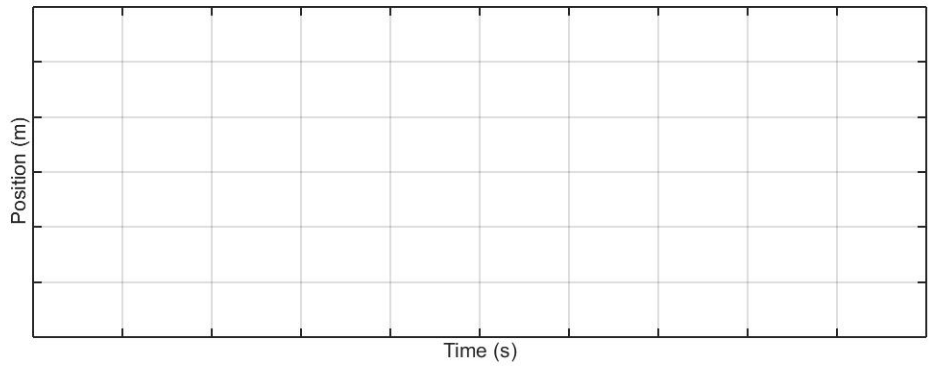
- IOLab
- smooth, surface at least 0.5 m long that can be inclined
- computer and IOLab software

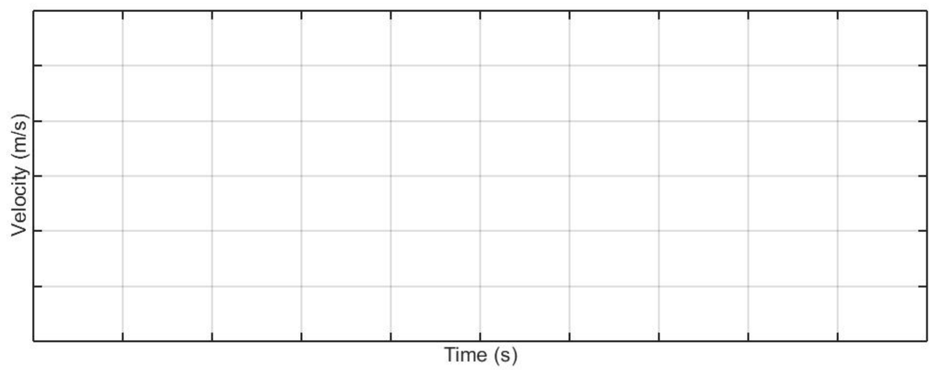
Activity 1-2: The Motion of the IOLab with a Constant Acceleration

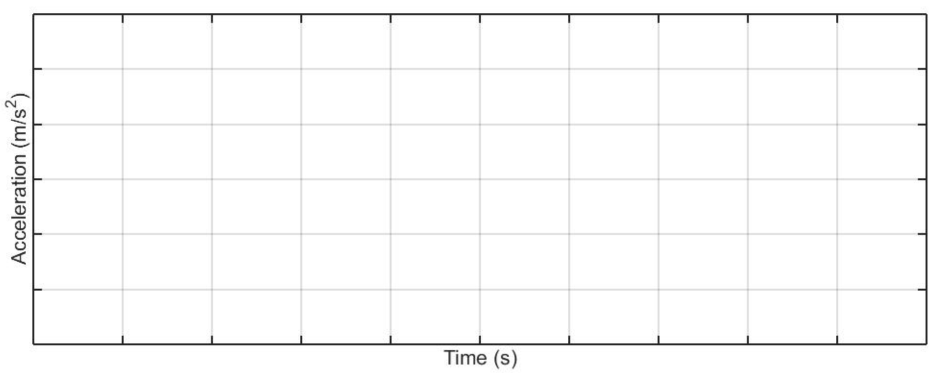
1. Set up the IOLab to collect data with the **Wheel** for **position**, **velocity** and **acceleration**.
2. Incline the ramp to an angle of about 20°.
3. Click the **Reverse y-axis box**.

4. Collect graphs of position, velocity and acceleration for the motion of the IOLab along the inclined ramp as you give it a short push up the ramp (in the positive y direction), release it and then stop it when it returns to its original position.
5. Keep copies of your graphs (print or save) and sketch your results on the RESULTS axes that follow. (Be sure that the graphs are labeled clearly.)

RESULTS







Question 1-3: Describe your graphs. Did they agree with your predictions?

Question 1-4: Would you describe this motion as having constant velocity or constant acceleration? Explain.

The motions of the IOLab examined in Activities 1-1 and 1-2 can be represented as functions of time by a series of mathematical equations called the kinematic equations. In the following activities, you will identify these equations.

Activity 1-3: Kinematic Equations for Motion with Constant Velocity (Zero Acceleration)

Below, you will find some equations that might represent the position, velocity, and acceleration of an object as functions of time,

Set #1	**Set #2**
(1) $x = x_0 + v_0 t$	(4) $x = x_0 + v_0 t + ½\, at^2$
(2) $v = v_0$	(5) $v = v_0 + at$
(3) $a = 0$	(6) a = constant

where:

x = position — v = instantaneous velocity

t = time — a = a constant acceleration along the x axis

x_0 = initial position at $t = 0$. (Tells you where the object was at the moment you started counting time.)

v_0 = initial velocity component at $t = 0$. (Tells you how fast the object was moving at the moment you started counting time.)

Question 1-5: Use your results from Activity 1-1 to determine which set of kinematic equations could be used to represent the motion of the IOLab along the horizontal table top where the x-axis is assumed to point along the line of motion. Explain your choice based on the graphs you obtained.

Question 1-6: Use your graphs from Activity 1-1, and the kinematic equations you chose in Question 1-5 to determine the values of x_0 and v_0. Explain how you found these values and what they represent.

Activity 1-4: Kinematic Equations for Motion with Constant Acceleration

Question 1-7: Use your results from Activity 1-2 to determine which set of kinematic equations could be used to represent the motion of the IOLab up and down the inclined ramp. Explain your choice based on the graphs of your data.

Question 1-8: Use your graphs from Activity 1-2, and the kinematic equations you chose in Question 1-7 to determine the values of x_0 and v_0. Explain how you found these values and what they represent.

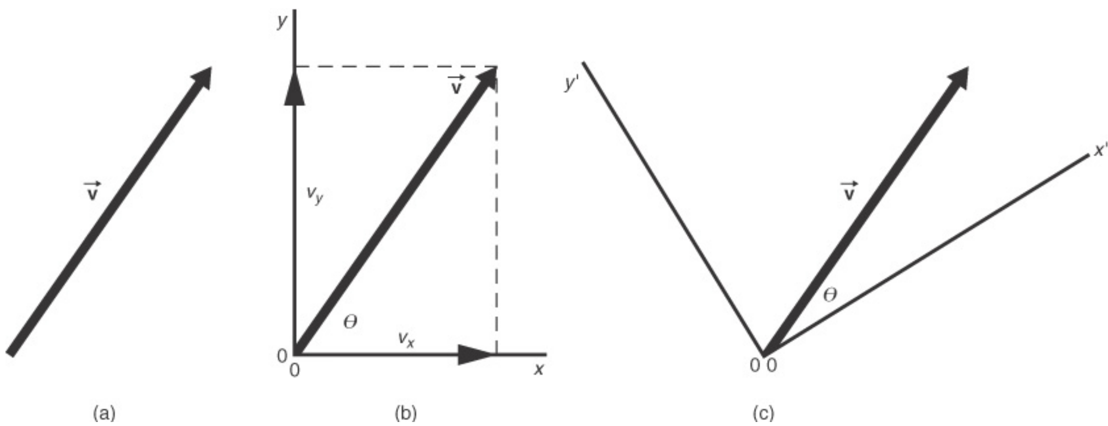
Question 1-9: Use your graphs from Activities 1-1 and 1-2 to determine the values of a for (a) the motion of the IOLab along the horizontal surface and (b) the motion of the IOLab moving up and down the inclined ramp.

(a) Motion in Activity 1-1:

(b) Motion in Activity 1-2:

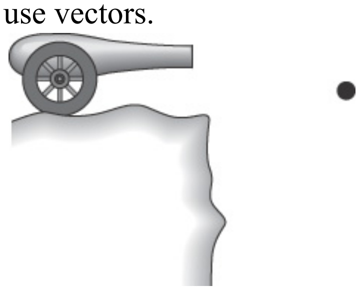
INVESTIGATION 2: TWO-DIMENSIONAL MOTION

The world is full of phenomena that we can know of directly through our senses—objects moving, pushes and pulls, sights and sounds, winds and waterfalls. A vector is a mathematical concept—a mere figment of the mathematician's fancy. But vectors can be used to describe aspects of "real" phenomena such as positions, velocities, accelerations, and forces. Vectors are abstract entities that follow certain rules. For example, in figure (a) below, the velocity of an object is represented by the vector, $\vec{v}$, which is drawn relative to two different sets of coordinate axes in (b) and (c).



A vector has two key attributes—magnitude and direction. The *magnitude* of a vector can be represented by the length of the arrow and its *direction* can be represented by the angle, θ, between the arrow and the coordinate axes chosen to help describe the vector.

In earlier labs you drew vectors in only one dimension. But vectors are especially useful in representing two-dimensional motion because they can be resolved into components. In the middle figure above, the velocity vector is resolved into x and y components. Added together, these components are equivalent to the original vector, but they can be analyzed *independently* of each other. This is one reason it is convenient to use vectors.



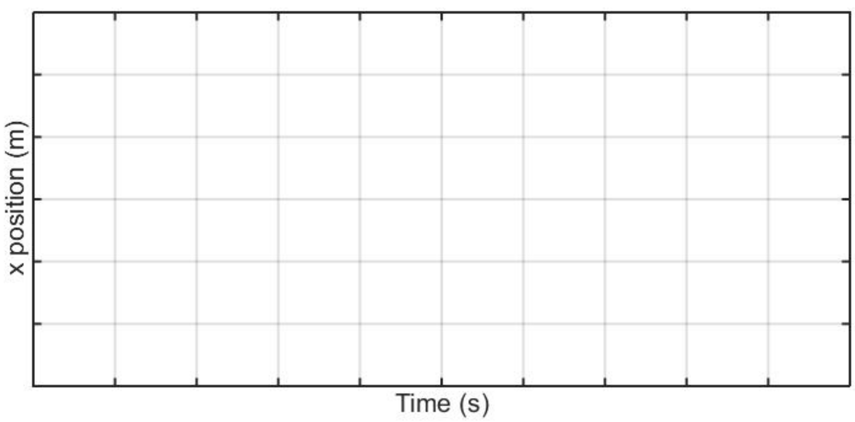
If a cannonball is shot off a cliff with a certain initial velocity in the x direction, the two-dimensional motion that results is known as *projectile motion*. The ball will continue to move forward in that direction and at the same time fall in the y direction as a result of the gravitational attraction between the Earth and the ball.

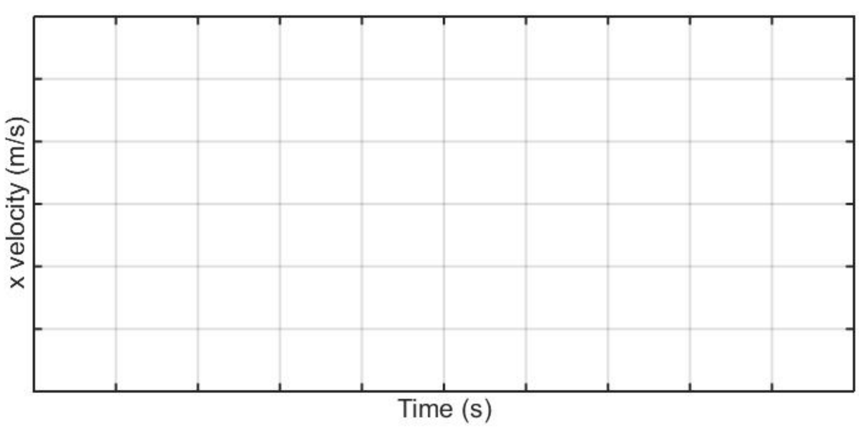
In this investigation you will examine the motion of a tennis ball that is tossed into the air so that it is moving in both the x and y directions. The toss of the ball and its trajectory are shown in the photos below.

Because the motion of the ball is in two dimensions, it is not possible to make measurements using the IOLab. Instead, you will use the method of video analysis to examine the motion and to determine the mathematical representations of the horizontal and vertical components of the motion. First some predictions:

Prediction 2-1: On the PREDICTION axes below, sketch your predictions for how the x-coordinate of the ball and the x-component of the velocity will vary with time. (Assume that the positive x direction in the photos is to the right.)

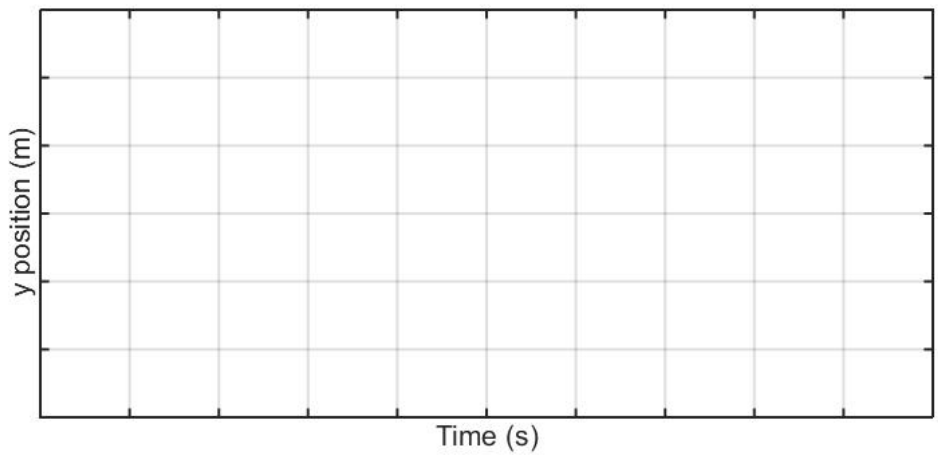
PREDICTION

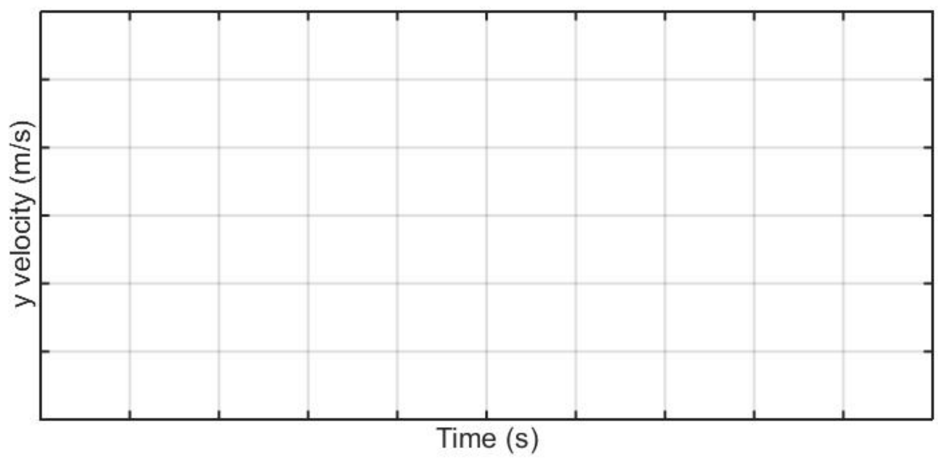




Prediction 2-2: On the PREDICTION axes below, predict how the *y*-coordinate of the ball and the *y*-component of the velocity will vary with time.

PREDICTION

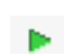




To test your predictions, you will need

- ***Tracker*** video analysis software. (See the Appendix on page 17 for directions on how to download and install ***Tracker***.)
- ***BallToss*** video

Activity 2-1: Horizontal Motion of a Projectile

1. Open ***Tracker***, and open the video ***Ball Toss***.
2. Play the video by clicking on the play arrow  at the bottom left, and observe the motion of the ball. Return the video to the first frame by clicking on , next to the play arrow.

Question 2-1: Describe the shape of the trajectory of the ball.

Note: If you ever need help with ***Tracker***, search the **Help** menu and select "Getting Started."

3. Set the scale of the measurements clicking on the calibration menu and by choosing **New>Calibration Stick**. Drag one end of the blue stick to the bottom of the pile of books, and the other end to the top. (Be sure that the stick is vertical—90°.) Type in the height of the books given in the first frame of the video in the **length** box at the top and hit **Return** (or **Enter** if you're using a PC). Use meters.

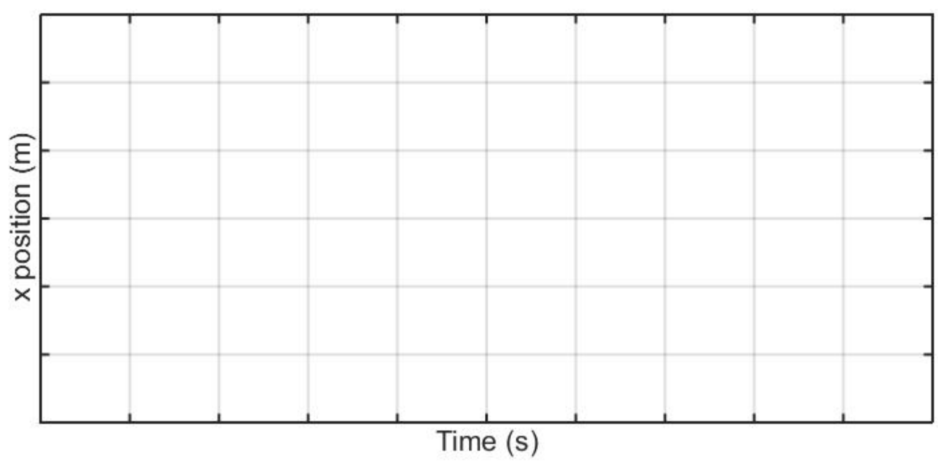
4. Click on to create a set of coordinate axes. These can be placed anywhere, but for simpler calculations, it is best to click and drag the origin to the center of the ball. Be sure that the **angle from horizontal** is 0.0°

5. To record the positions of the ball in all frames, select **New>Point Mass** from the **Track** menu. Now, hold down the **Shift** key, position the cursor on the center of the ball, and click. Repeat this for all frames of the video. (The video will advance frame-to-frame automatically.)

6. When you are done, return to the first frame by clicking on , and play the video again to see the trajectory of the ball traced out as the video plays.

7. To find the graph for x vs. time, click on the label of the vertical axis on the graph, and select **x: position x-component**. Save a copy (print or save) and sketch the graph on the RESULTS axes below.

RESULTS



Question 2-2: Does the graph for x vs. time agree with your Prediction 2-1? Explain.

Question 2-3: Does the graph for x vs. time represent motion with a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

8**.** Choose the kinematic equation on page 7 that describes x vs. time for this motion, and **model** it in the software to find the values of the parameters in that equation, e.g., v_0 and x_0. Here are the steps in ***Tracker***:

a. Pull down the **Track** menu, and select **New>Kinematic Particle Model**.

b. Near the bottom of the window, you will see columns for **Name** and **Expression**. **Double click** on the **Expression** box next to **x**.

c. Now, enter a mathematical expression to represent x as a function of time. For example, set 1 on page 7 gives $x = x_0 + v_0t$. You must determine x_0 and calculate v_{0x} based on your data for Mass A. **Note:** multiplication must be stated explicitly (i.e. '4*t' instead of '4t').

d. Select a color different than **Mass A** by again pulling down the **Track** menu, selecting **Model A** and then **Color**, and choosing a different color.

e. You can display the graphs of **Mass A** (the ball tracked in the video) and **Model A** on the same graph axes by right clicking (cntrl click on a Mac) the plot area, selecting **Compare with** on the pull-down menu, and then selecting **Mass A**.

f. Compare the two graphs, and try to determine what needs to be changed in the **Model A** equation to get its graph to match as closely as possible to the **Mass A** graph measured from the video. Select **Model A** and then **Model Builder** from the pull down **Track** menu, double click on the equation and change it.

g. Repeat (f) until the **Mass A** and **Model A** graphs match very well.

Question 2-4: Based on your mathematical model, what is the kinematic equation for x vs. t? What are the values (from your mathematical model) for v_0 and x_0? What are the meanings of these two values?

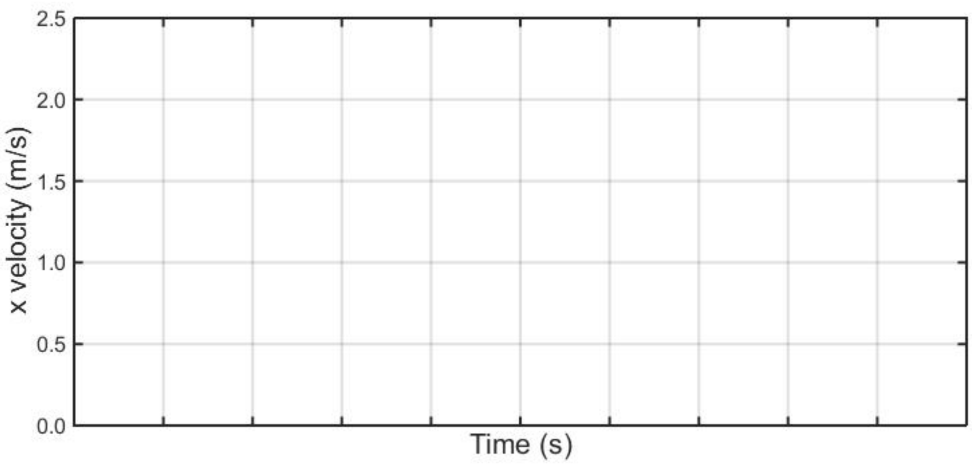
9. Use  to return to the first frame of the video. Play the video and observe both the motion of **Mass A** and the x-motion from **Model A** plot out.

Question 2-5: Based on what you observe with **Model A**, describe the x-motion of the ball in the video. Is it with constant velocity, constant acceleration or some other motion? Explain.

10. Now, display the graph of v_x vs. time for **Mass A** by selecting **vx: velocity x-component** from the vertical menu on the graph. (Be sure that **Mass A** is selected next to **Plot** at the top of the graph.) There may be a lot of noise (spikes) on this graph. Adjust the vertical axis to something like 0 to 5 m/s to better see the overall trend of vx vs. time.

11. Keep a copy of the graph (print or save) and sketch on the RESULTS axes that follow.

RESULTS



Question 2-6: Why was there so much noise on this graph? What does it have to do with the way the positions of the ball were determined in each frame of the video?

Question 2-7: Does the graph for v_x vs. time agree with your Prediction 2-1? Explain.

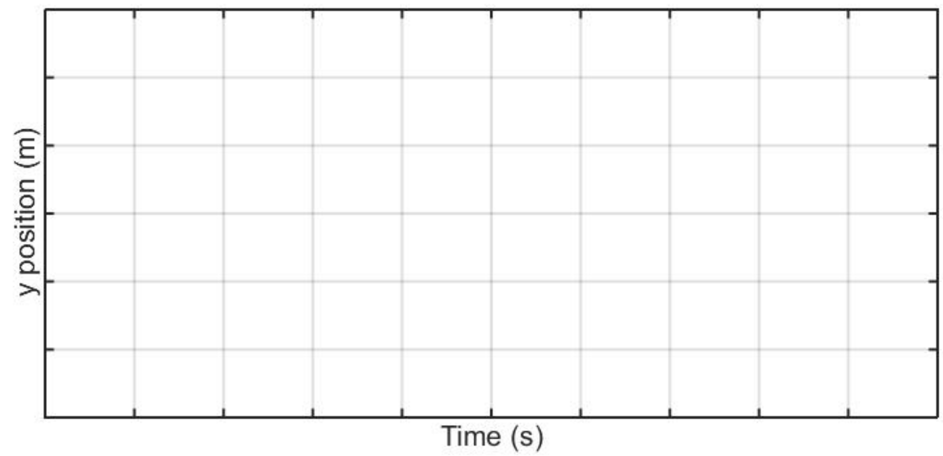
Question 2-8: Does the graph for v_x vs. time represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

Question 2-9: What is the kinematic equation for v_x vs. time? Give the values of all parameters taken from your graph.

Activity 2-2: Vertical Motion of a Projectile

1. Display the graph of y vs. time for **Mass A** by selecting **y: position y-component** from the vertical menu on the graph. (Be sure that **Mass A** is selected next to **Plot** at the top of the graph.) Keep the graph and sketch on the RESULTS axes below.

RESULTS



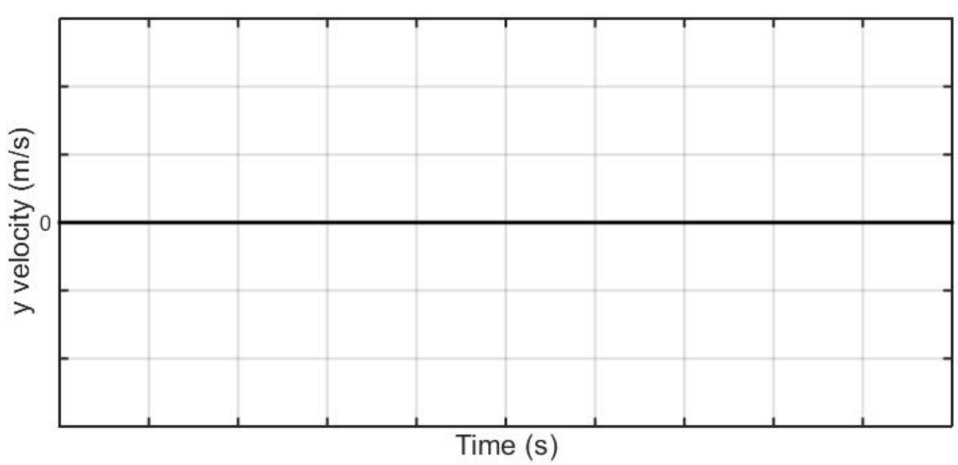
Question 2-10: Does the graph for *y* vs. time agree with your Prediction 2-2? Explain.

Question 2-11: Does the graph for *y* vs. time represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

Question 2-12: What is the value for y_0, the initial *y* coordinate of the ball? Why does y_0 have this value?

2. Display the graph of v_y vs. time. Keep the graph and sketch on the RESULTS axes below.

RESULTS



Question 2-13: Does the graph for v_y vs. time agree with your Prediction 2-2? Explain.

Question 2-14: Does the graph for v_y vs. t represent motion at a constant velocity or constant acceleration? How do you know? Refer back to your observations in Investigation 1, if necessary.

3. Rather than more or less guessing to see what looks good, you can also do a fit to the data with Tracker. In order to find the parameters e.g., v_{oy} and a_y in the equation:
   a. Right click on the graph area (cntrl click on a Mac), and select **Analyze** from the menu. The graph will appear in a new window.
   b. Click **Analyze** in the upper lefthand corner, and below the graph axes, select **Line** for **Fit Name** .
   c. You can change the color of the fit line clicking on the  near the top of the table on the right in the **Analyze** window, and selecting a new color.
   d. You can click the data line on and off to make the view of the fit easier by checking and un-checking the **lines** box in the v_y column.

Question 2-15: What is the kinematic equation?

Question 2-16: What is the value of v_0,, the initial y-component of velocity of the ball? What is the meaning of this?

Question 2-17: What is the value of the y component of the acceleration of the ball, a_y? Is this value what you expected? Explain.

Question 2-18: Use your observations in the two investigations of this lab to justify the statement that projectile motion is a combination of horizontal motion at a constant velocity (zero acceleration) and vertical motion with a constant (gravitational) acceleration.

Appendix: Installing and Using *Tracker*

(1) Go to http://www.opensourcephysics.org/items/detail.cfm?ID=7365

(2) Download the ***Tracker*** version for your system: Windows, OS X or Linux.

(3) You can find Help with installing ***Tracker*** at http://physlets.org/tracker/installers/installer_help.html

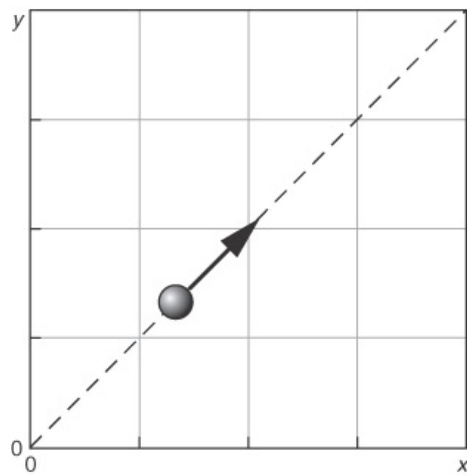
(4) You can find information on Getting Started with ***Tracker*** at http://physlets.org/tracker/help/frameset.html

(5) You can find a Tutorial on how to use ***Tracker*** at https://www.youtube.com/watch?v=La3H7JywgX0

(6) Important Note: ***Tracker*** requires Java 1.6 or higher. ***Tracker*** also supports QuickTime 7 (Windows/Mac only). **Important note for Windows users**: do not install QuickTime 7.7.6 or later as it will UNINSTALL QuickTime for Java! Instead, use the QuickTime 7.7.4. installer which you can download here.

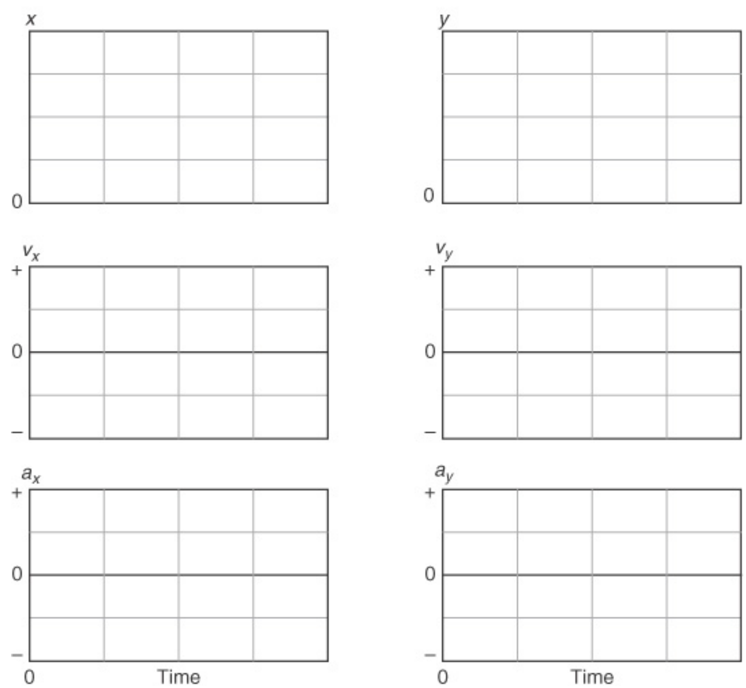
Homework for Lab 8:
Two-Dimensional Motion (Projectile Motion)

1. A heavy ball is released at the origin, and moves at a constant velocity on a *horizontal* floor along the dashed line shown below.



a. Is this projectile motion? Explain your answer.

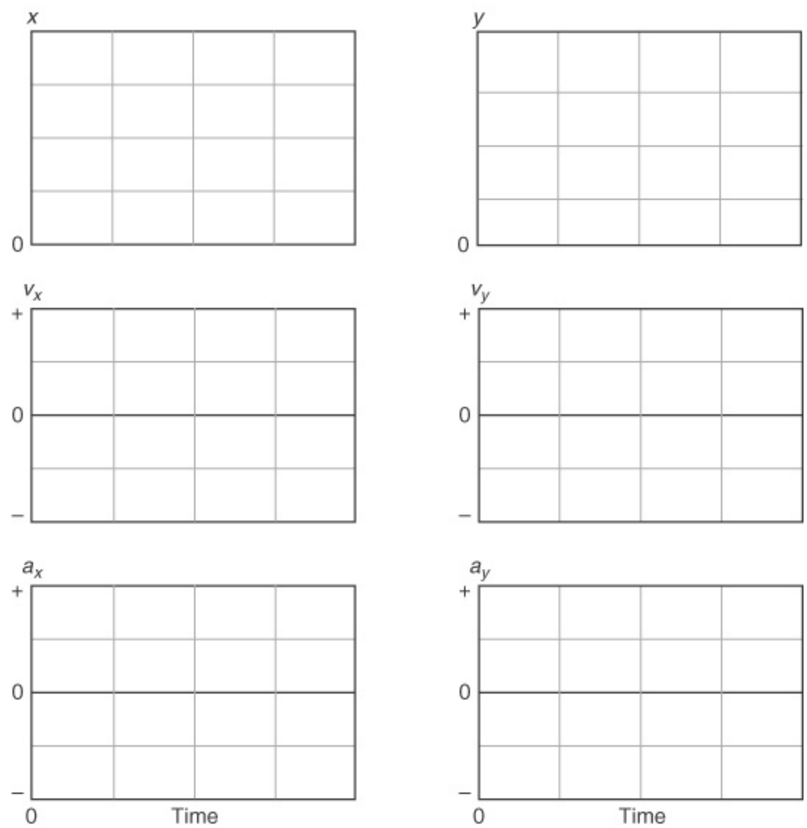
b. On the axes that follow sketch the x and y components of the position, velocity, and acceleration of the ball as functions of time.



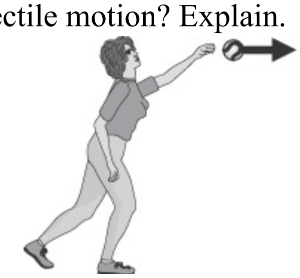
2. The ball in Question 1 begins *at rest* at the origin. It is tapped repeatedly by two students using batons. They alternate tapping in the x and y directions. (**Note:** These taps provide approximately constant forces in the x and y directions.) The ball follows the same dashed path as the ball that rolls freely on the floor.

a. According to the definition of projectile motion, is the tapped ball undergoing projectile motion? Why or why not?

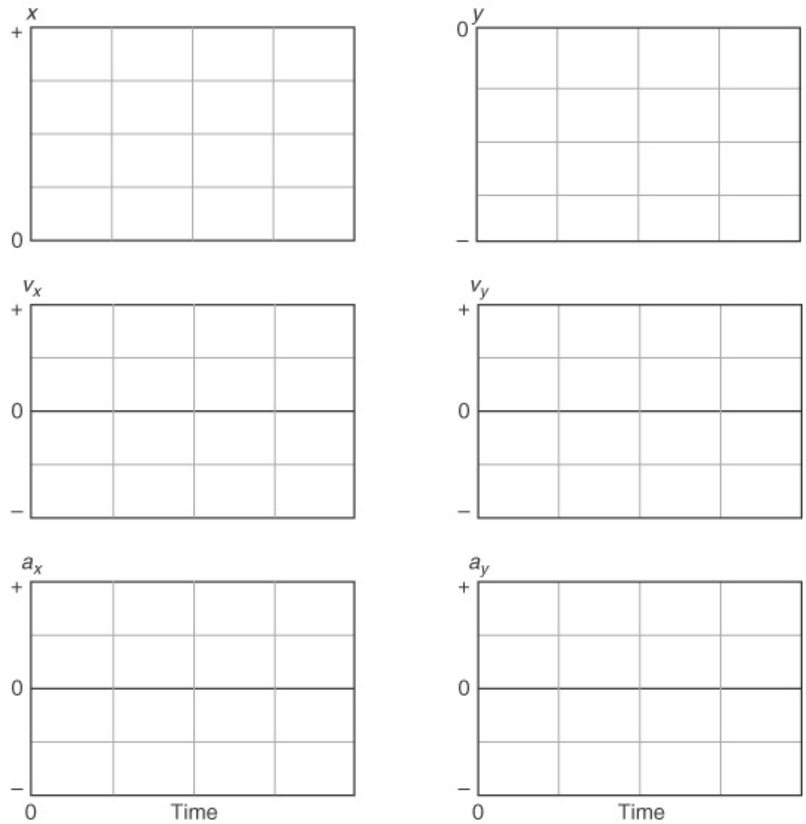
b. Sketch on the axes that follow the x and y components of the position, velocity, and acceleration of the ball as functions of time.



3. A pitcher throws a baseball. She releases it so that it is initially moving in the horizontal direction, as shown in the figure that follows. Is the motion of the ball after it leaves her hand projectile motion? Explain.



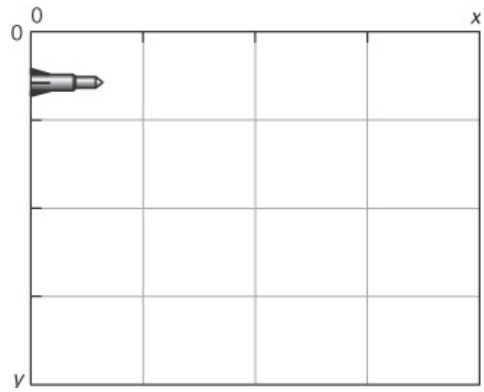
Assuming that air resistance is negligible, sketch the x and y components of the position, velocity, and acceleration of the ball as functions of time on the axes that follow. (Assume that the origin of the coordinate system is at the point she releases the ball.)



4. A ball is moving through the air. The data in the table that follows are either the *x* or *y* position coordinates of the ball as a function of time. (The positive *y* axis is upward.) Use these data to find velocities as a function of time, and determine from the velocities whether these data are *x* or *y* coordinates. Be sure to explain thoroughly how you reached your conclusion. (You may wish to **plot a graph.**)

Time (s)	**Position m)**
0.00	5.00
0.20	7.80
0.40	10.22
0.60	12.24
0.80	13.86
1.00	15.10
1.20	15.94
1.40	16.40
1.60	16.46
1.80	16.12
2.00	15.40

5. Suppose a rocket in outer space is thrust along the y direction with an acceleration of 15 m/s^2 while moving freely (no applied force) in the x direction. Sketch below the path followed by the rocket.



Is this motion similar to projectile motion? Explain.