

LABORATORY II

DESCRIPTION OF MOTION IN TWO DIMENSIONS

In this laboratory you continue the study of accelerated motion in more situations. The carts you used in Laboratory I moved in only one dimension. However, as you know, objects don't *always* move in a straight line! However, motion in two and three dimensions can be decomposed into one-dimensional motions; what you learned in the first lab can be applied to this lab.

You will study the motions of an object in free fall and an object tossed into the air. In these labs, you will need to consider the effects of *air resistance* on the motion of the objects. Can it always be neglected? As always, if you have any questions, talk with your fellow students or your instructor.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Determine the motion of an object in free-fall by considering what quantities and initial conditions affect the motion.
- Determine the motion of a projectile from its horizontal and vertical components by considering what quantities and initial conditions affect the motion.

PREPARATION:

Read Serway & Vuille Chapter 2 section 2.6 and Chapter 3. Review your results and procedures from Laboratory I. Before coming to the lab you should be able to:

- Determine instantaneous and average velocities and accelerations from video images.
- Analyze a vector in terms of its components along a set of perpendicular axes.
- Add and subtract vectors.

PROBLEM #1: MASS AND THE ACCELERATION OF A FALLING BALL

The local fire station in California has enlisted your help in studying the dropping of balls of chemicals from helicopters to extinguish forest fires. The amount of chemicals in one of these balls is varied depending on the size of the fire. As a first step to your study, you assume the helicopters are stationary, hovering over a fire. You are to determine if balls of the same size with different amounts of chemicals will fall differently.

EQUIPMENT

For this problem you will have a collection of balls each with approximately the same diameter but different masses. You will also have a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

Sketch how you expect the *acceleration vs. mass graph* to look for balls dropped from rest with the same size and shape, but having different masses.

Do you think the free-fall acceleration **increases**, **decreases**, or **stays the same** as the mass of the object increases? Explain your reasoning. (Remember that the shape of the ball does not change.)

WARM-UP

Read: Serway & Vuille Chapter 2 Section 2.6

1. Sketch a graph of *instantaneous acceleration vs. time* for a falling ball. Next to this graph sketch a graph of *instantaneous acceleration vs. time* for a heavier falling ball that has the same size and shape. Explain your reasoning for each graph. Write down an equation for each graph. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?
2. Use your acceleration vs. time graphs to sketch *instantaneous velocity vs. time graphs* for a light and heavy ball using the same scale for the time axes. Write down an equation for each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of the constants be determined from the equations representing the acceleration vs. time graphs?
3. Use your velocity vs. time graphs to sketch *instantaneous position vs. time graphs* for each case using the same scale for the time axes. Write down an equation for each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of these constants be determined from the equations representing the acceleration vs. time or velocity vs. time graphs?

4. How could you determine the acceleration of a falling ball from video data (graphs and equations for position and velocity)? Write down an outline for how to do this, based on your experiences in Lab I.
5. Do you expect that a heavier ball will have a higher, lower, or equal acceleration as a lighter ball of the same size? Is the relationship linear, or curved? Use this to predict a graph of *acceleration vs. mass* for falling balls.
6. Use the simulation "Lab2Sim" (See Appendix F for a brief explanation of how to use the simulations) to explore the approximate conditions of your experiment. Look at the graphs produced through simulated freefall. (The initial position of the ball should be well off the table, and the initial speed should be zero. Note that the initial position and velocity parameters in Lab2Sim are specified as vectors of the form $\langle x_0, y_0, z_0 \rangle$ and $\langle v_{x0}, v_{y0}, v_{z0} \rangle$. The x-axis is along the Right/Left direction, the y-axis is Up/Down, and the z-axis is Front/Back.) If you believe air resistance may affect your results, explore the effects with the simulation. Check the graphs of position and velocity with various values for air resistance. Test the effects of a large air resistance on the ball's velocity and acceleration. If you believe that uncertainty in position measurements may affect your results, use the simulation to compare the results with and without error. Note the difference in effect on the position vs. time graph and the velocity vs. time graph.

EXPLORATION

Review your lab journal from the problems in Lab 1. Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice dropping one of the balls until you can get its motion to fill the least distorted part of the screen. Determine how much time it takes for the ball to fall and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position and screen size to give you enough data points. You should be able to reproduce the conditions described in the Predictions.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might hold an object of known length *in the plane of motion* of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object in the video image? The best place to put the reference object to determine the distance scale is at the position of the falling ball.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame. Write down your measurement plan.

MEASUREMENT

Measure the mass of the ball and make a video of its fall according to the plan you devised in the exploration section. Make sure you can see the ball in every frame of the video.

Digitize the position of the ball in enough frames to accomplish your analysis. Set the scale for the axes of your graph so that you can see the data points as you take them. Use your measurements of total distance the ball travels and total time to determine the maximum and minimum value for each axis before taking data.

Complete your data analysis as you go along (before making the next video), so you can determine how many different videos you need to make and what the object's mass should be for each video. Don't waste time collecting data you don't need or, even worse, incorrect data. Repeat this procedure for more balls with different masses. Collect enough data to convince yourself and others of your conclusion.

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs in the x and y directions. How can you estimate the values of the constants of each function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the velocity vs. time graphs in the x and y directions. Compare these functions with the position vs. time functions. Determine the acceleration of the ball for different masses. Is the average acceleration different for the beginning of the video (when the object is moving slowly) and the end of the video (when the object is moving fast)?

Determine the average acceleration of the object in free fall for each value of its mass and use this to make a graph of the acceleration vs. mass. Is the average acceleration of the ball equal to its instantaneous acceleration in this case? Do you have enough data to convince others of your conclusions about your predictions? If the accelerations turn out to be dependent on mass, what might be the reason for the difference?

CONCLUSION

How does the acceleration of a freely falling object depend on its mass? Did the data from the video images support your predicted relationship between acceleration and mass? (Make sure you carefully review *Appendix C* to determine if your data really supports this relationship.) If your data did not support your prediction, were your predictions wrong or were your results unreliable? Explain your reasoning.

How does the acceleration you found compare to the gravitational acceleration? Can you explain any differences? What are the limitations on the accuracy of your measurements and analysis?

If your results did not completely match your expectations, you should use the simulation “Lab2Sim” (See *Appendix F* for a brief explanation of how to use the simulations) to explore what might have happened.

PROBLEM #2: ACCELERATION OF A BALL WITH AN INITIAL VELOCITY

You have designed an apparatus to measure air quality in your city. To quickly force air through the apparatus, you will launch it straight downward from the top of a tall building. A very large acceleration may destroy sensitive components in the device; the launch system's design ensures that the apparatus is protected during its launch. You wonder what the acceleration of the apparatus will be once it exits the launcher. Does the object's acceleration after it has left the launcher depend on its velocity when it leaves the launcher? You decide to model the situation by throwing balls straight down. The "launcher" is your hand.

EQUIPMENT

You will have a ball, a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL applications).

PREDICTION

Sketch a graph of a ball's acceleration as a function of time after it is launched downward with an initial velocity. State how your graph will change if the object's initial velocity increases or decreases.

Do you think that the acceleration **increases**, **decreases**, or **stays the same** as the initial velocity of the object increases? Make your best guess and explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 2, Section 2.6

1. Sketch a graph of *acceleration vs. time* for a ball dropped from rest (refer to the Warm-up questions from the previous lab problem). Next to this graph, sketch the *acceleration vs. time* for a ball launched downward with an initial velocity. How are these graphs similar or different? Explain your reasoning. Write down the equation that best represents each graph. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graph?
2. Write down the relationships between the acceleration and the velocity and the velocity and the position of the ball. Use these relationships to construct the graphs for *velocity vs. time* and *position vs. time* just below each acceleration graph from question 1. Use the same scale for each time axis. Write down the equation that best represents each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graphs? Can any of the constants be determined from the equations representing the acceleration graphs?

3. How will you determine the acceleration of a falling ball from video data (graphs and equations for position and velocity)? Write down an outline for how to do this, based on your experiences in previous labs.
4. Explain how you expect the initial launch velocity to affect the acceleration of the ball.
5. Use the simulation "Lab2Sim" to approximate the conditions of your experiment. (See Appendix F for a brief explanation of how to use the simulations.) Do multiple runs of the simulations with various initial velocities and compare graphs. (The initial position of the ball should be well off the table, and the initial speed should be downward. Note that the initial position and velocity parameters in Lab2Sim are specified as vectors of the form $\langle x_0, y_0, z_0 \rangle$ and $\langle v_{x0}, v_{y0}, v_{z0} \rangle$. The x-axis is along the Right/Left direction, the y-axis is Up/Down, and the z-axis is Front/Back.) If you believe air resistance may have affected your results, explore the effects of each with the simulation. If you believe that uncertainty in position measurements may have affected your results, use the simulation to compare the results with and without error. Compare the effect of error in the position vs. time graph with the velocity vs. time graph.

EXPLORATION

Review your lab journal from Lab 1. Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice throwing the ball straight downward until you can get the ball's motion to fill most of the video screen **after** it leaves your hand. Determine how much time it takes for the ball to fall and estimate the number of video points you will get in that time. Is it sufficient to make the measurement? Adjust the camera position to get enough data points.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might hold an object of known length *in the plane of motion* of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object in the video image? The best place to put the reference object to determine the distance scale is at the position of the falling ball.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame.

Write down your measurement plan.

MEASUREMENT

Make a video of the ball being tossed downwards according to your measurement plan from the Exploration section.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. Make sure you set the scale for the axes of your graph so that you can see the data points as you take them. Use your measurements of total distance the ball travels and total time to determine the maximum and minimum value for each axis before taking data.

Graph your data as you go along (before making the next video), so you can determine how many different videos you need to make and how you should change the ball's initial velocity for each video. Don't waste time collecting data you don't need or, even worse, incorrect data. Collect enough data to convince yourself and others of your conclusion.

Repeat this procedure (with the same ball) for different launch velocities.

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs in the x and y directions. How can you estimate the values of the constants of each function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the velocity vs. time graphs in the x and y directions. Compare these functions with the position vs. time functions. Determine the launch velocity of the ball from this graph. Is this value reasonable?

From the velocity vs. time graph(s) determine the acceleration of the ball. Use the function representing the velocity vs. time graph to calculate the acceleration of the ball as a function of time. Is the average acceleration different for the beginning of the video (just after launch) and the end of the video?

If you cannot get one function to describe your velocity graph in a consistent way, you can try using one function for the first half of the motion and another for the last half. To do this you must go through the video analysis process twice and record your results each time. (How can you avoid repeating some work with the "Save Session" and "Open Session" commands?)

Determine the acceleration of the ball just after launch and at the end of the video. How do they compare with the gravitational acceleration? Do you have enough data to convince others of your conclusions about your predictions?

Repeat the analysis for another launch velocity and compare the results.

CONCLUSION

Did the data support your predicted relationship between acceleration and initial velocity? (Make sure you carefully review *Appendix C* to determine if your data really supports this relationship.) If not, what assumptions did you make that were incorrect. Explain your reasoning.

What are the limitations on the accuracy of your measurements and analysis?

Will the survival of your apparatus depend on its launch velocity? State your results in the most general terms supported by your analysis.

SIMULATION

If your results did not completely match your expectations, you may use the simulation “Lab2Sim” (See Appendix F for a brief explanation of how to use the simulations) to explore what might have happened.

PROBLEM #3: PROJECTILE MOTION AND VELOCITY

In medieval warfare, probably the greatest technological advancement was the trebuchet, which slings rocks into castles. You are asked to study the motion of such a projectile for a group of local enthusiasts planning a war reenactment. Unfortunately an actual trebuchet had not been built yet, so you decide to first look at the motion of a thrown ball as a model of rocks thrown by a trebuchet. Specifically, you are interested in how the horizontal and the vertical components of the velocity for a thrown object change with time.

EQUIPMENT

For this problem you will have a ball, a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

1. Make a rough sketch of how you expect the graph of the *horizontal velocity vs. time* to look for the thrown object. Do you think the horizontal component of the object's velocity **changes** during its flight? If so, how does it change? Or do you think it is **constant**? Explain your reasoning.
2. Make a rough sketch of how you expect the graph of the *vertical velocity vs. time* to look for the object. Do you think the vertical component of the object's velocity **changes** during its flight? If so, how does it change? Or do you think it is **constant**? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 3, Sections 3.1 to 3.4

1. Make a large (about one-half page) rough sketch of the trajectory of the ball after it has been thrown. Draw the ball in at least five different positions; two when the ball is going up, two when it is going down, and one at its maximum height. Label the horizontal and vertical axes of your coordinate system.
2. On your sketch, draw and label the expected acceleration vectors of the ball (relative sizes and directions) for the five different positions. Decompose each acceleration vector into its vertical and horizontal components.
3. On your sketch, draw and label the velocity vectors of the object at the same positions you chose to draw your acceleration vectors. Decompose each velocity vector into its vertical and horizontal components. Check to see that the changes in the velocity vector are consistent with the acceleration vectors.
4. Looking at your sketch, how do you expect the ball's *horizontal acceleration* to change with time? Write an equation giving the ball's horizontal acceleration as a function of time.

Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

5. Looking at your sketch, how do you expect the ball's *horizontal velocity* to change with time? Is it consistent with your statements about the ball's acceleration from the previous question? Write an equation for the ball's horizontal velocity as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?
6. Write an equation for the ball's *horizontal position* as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Are any of these constants related to the equations for horizontal velocity or acceleration?
7. Repeat Warm-up questions 4-6 for the *vertical* component of the acceleration, velocity, and position. How are the constants for the acceleration, velocity and position equations related?
8. Use the simulation "Lab2Sim" to simulate the projectile motion in this problem. Note that in this case the initial velocity should have non-zero horizontal and vertical components.

EXPLORATION

Review your lab journal from the problems in Lab 1.

Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice throwing the ball until you can get the ball's motion to fill the video screen (or at least the undistorted part of the video screen) **after** it leaves your hand. Determine how much time it takes for the ball to travel and estimate the number of video points you will get in that time. Is that enough points to make the measurement? Adjust the camera position to give you enough data points.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might need to place an object of known length in the plane of motion of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object? Determine the best place to put the reference object for calibration.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image of the ball due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame.

Write down your measurement plan.

MEASUREMENT

Measure the total distance the ball travels and total time to determine the maximum and minimum value for each position axis before taking data with the computer.

Make a video of the ball being tossed. Make sure you can see the ball in every frame of the video.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. Set the scale for the axes of your graph so that you can see the data points as you take them.

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs in the x and y directions. How can you estimate the values of the constants of each function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the velocity vs. time graphs in the x and y directions. Compare these functions with the position vs. time functions. How can you calculate the values of the constants of these functions from the functions representing the position vs. time graphs? You can also estimate the value of the constants from the graph. What kinematics quantities do these constants represent?

From the velocity vs. time graph(s) determine the acceleration of the ball independently for each component of the motion as a function of time. What is the acceleration of the ball just after it is thrown, and just before it is caught? What is the magnitude of the ball's acceleration at its highest point? Is this value reasonable?

Determine the launch velocity of the ball from the velocity vs. time graphs in the x and y directions. Is this value reasonable? Determine the velocity of the ball at its highest point. Is this value reasonable?

CONCLUSION

Did your measurements agree with your initial predictions? Why or why not? If they do not agree, are there any assumptions that you have made, that might not be correct? What are the limitations on the accuracy of your measurements and analysis?

How does the horizontal velocity component of a launched rock depend on time? How does the vertical velocity component of depend on time? State your results in the most general terms supported by your analysis. At what position does the ball have the minimum velocity? Maximum velocity?

If your results did not completely match your expectations, you should go back and use the simulation "Lab2Sim" again.

PROBLEM #4: PROJECTILE MOTION AND MASS

We now extend the study started in Problem #3. Understandably, it was hard to find rocks of the same mass to launch using a trebuchet during medieval times. The second part of your study requires you to determine if the mass of an object would affect your conclusions in Problem #3. Specifically, you want to determine how the horizontal and vertical components of the velocity of a thrown object depend on its mass.

EQUIPMENT

For this problem you will have a collection of balls each with approximately the same diameter but different masses. You will also have a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTIONS

1. Make a rough sketch of how you expect the graph of the horizontal component of *acceleration vs. mass* to look for the object in projectile motion. Do you think the horizontal component of an object's acceleration will **increase**, **decrease**, or **stay the same** as the mass of that object increases? Explain your reasoning.
2. Make a rough sketch of how you expect the graph of the vertical component of *acceleration vs. mass* to look for the object in projectile motion. Do you think the vertical component of an object's acceleration will **increase**, **decrease**, or **stay the same** as the mass of that object increases? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 3, Sections 3.1 to 3.4

|| If you have done Problem #3, skip Questions 1 - 7 and review your notes from that problem.

1. Make a large (about one-half page) rough sketch of the trajectory of the ball after it has been thrown. Draw the ball in at least five different positions; two when the ball is going up, two when it is going down, and one at its maximum height. Label the horizontal and vertical axes of your coordinate system.
2. On your sketch, draw and label the expected acceleration vectors of the ball (relative sizes and directions) for the five different positions. Decompose each acceleration vector into its vertical and horizontal components.
3. On your sketch, draw and label the velocity vectors of the object at the same positions you chose to draw your acceleration vectors. Decomposes each velocity vector into its vertical and horizontal components. Check to see that the changes in the velocity vector are consistent with the acceleration vectors.

4. Looking at your sketch, how do you expect the ball's *horizontal acceleration* to change with time? Write an equation giving the ball's horizontal acceleration as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?
5. Looking at your sketch, how do you expect the ball's *horizontal velocity* to change with time? Is it consistent with your statements about the ball's acceleration from the previous question? Write an equation for the ball's horizontal velocity as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?
6. Write an equation for the ball's *horizontal position* as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Are any of these constants related to the equations for horizontal velocity or acceleration?
7. Repeat Warm-up questions 4-6 for the *vertical* component of the acceleration, velocity, and position. How are the constants for the acceleration, velocity and position equations related?
8. How are the components of the acceleration of a projectile related to the mass of the object? How are the components of the velocity related to mass?

EXPLORATION

|| If you have done Problem #3, the following is a review -- you need only do what you feel is necessary.

Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice throwing the ball until you can get the ball's motion to fill the video screen (or at least the undistorted part of the video screen) **after** it leaves your hand. Determine how much time it takes for the ball to travel and estimate the number of video points you will get in that time. Is that enough points to make the measurement? Adjust the camera position to give you enough data points.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might need to place an object of known length in the plane of motion of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object? Determine the best place to put the reference object for calibration.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image of the ball due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame.

Write down your measurement plan.

MEASUREMENT

|| If you have done Problem #3, the following is a review.

A way to save time in this lab is for each group in your class to determine the horizontal and vertical acceleration for a **different** mass and report their findings to the class. You should be able to draw a sketch of the horizontal and vertical components of the acceleration vs. mass of the object from the data collected by the class.

If you are not using data from other groups analyzing different balls, you yourself will have to use several different balls of different masses. Use your experience from Problem #1 to determine which balls and how many are needed.

Measure the total distance the ball travels and total time to determine the maximum and minimum value for each position axis before taking data with the computer. Make a video of the ball being tossed. Make sure you can see the ball in every frame of the video.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. Set the scale for the axes of your graph so that you can see the data points as you take them.

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs in the x and y directions. How can you estimate the values of the constants of each function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the velocity vs. time graphs in the x and y directions. Compare these functions with the position vs. time functions. How can you calculate the values of the constants of these functions from the functions representing the position vs. time graphs? You can also estimate the value of the constants from the graph. What kinematics quantities do these constants represent?

From the velocity vs. time graph(s) determine the acceleration of the ball independently for each component of the motion as a function of time. What is the acceleration of the ball just after it is thrown, and just before it is caught? What is the magnitude of the ball's acceleration at its highest point? Is this value reasonable?

Determine the launch velocity of the ball from the velocity vs. time graphs in the x and y directions. Is this value reasonable? Determine the velocity of the ball at its highest point. Is this value reasonable?

Report the value of your object's mass (with uncertainty) and its horizontal and vertical accelerations as a function of time to the class. Also report the object's average acceleration for each component (with uncertainties) to the class and record the values from other groups. Make graphs of horizontal and vertical acceleration vs. mass.

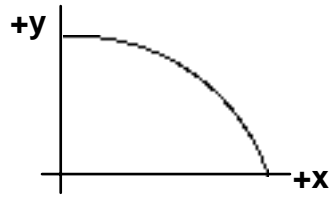
CONCLUSION

How does the horizontal component of a projectile's acceleration depend on its mass? How does the vertical component of the acceleration depend on mass? State your result in the most general terms supported by your analysis. Did your measurements agree with your initial predictions? Why or why not?

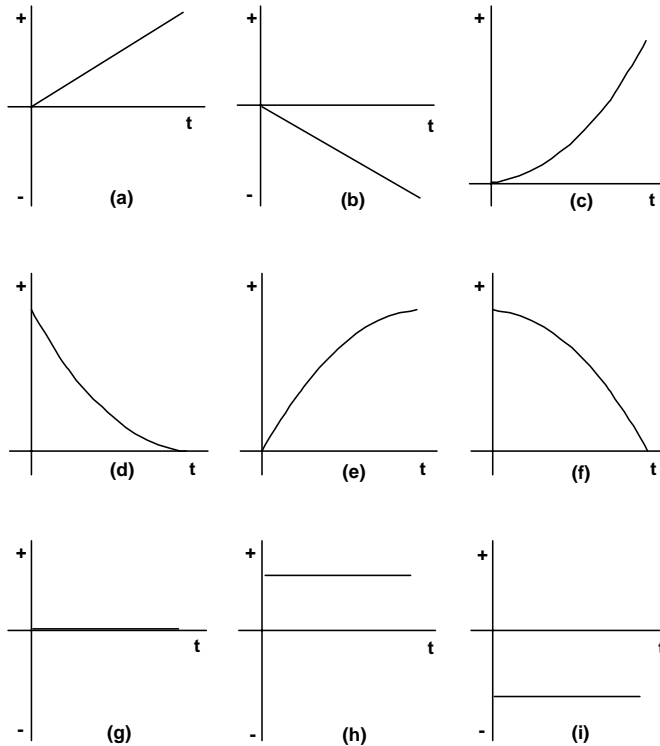
How does your conclusion tie together with your results from previous problems? What are the limitations on the accuracy of your measurements and analysis?

CHECK YOUR UNDERSTANDING:

1. A baseball is hit horizontally with an initial velocity v_0 at time $t_0 = 0$ and follows the parabolic arc shown at right.



- Which graph below best represents its horizontal position (x) versus time graph? Explain your reasoning.
- Which graph below best represents the horizontal velocity (v_x) versus time graph? Explain your reasoning.
- Which graph below best represents the horizontal acceleration (a_x) versus time graph? Explain your reasoning.
- Which graph below best represents the vertical position (y) versus time graph? Explain your reasoning.
- Which graph below best represents the vertical velocity (v_y) versus time graph? Explain your reasoning.
- Which graph below best represents the vertical acceleration (a_y) versus time graph? Explain your reasoning.

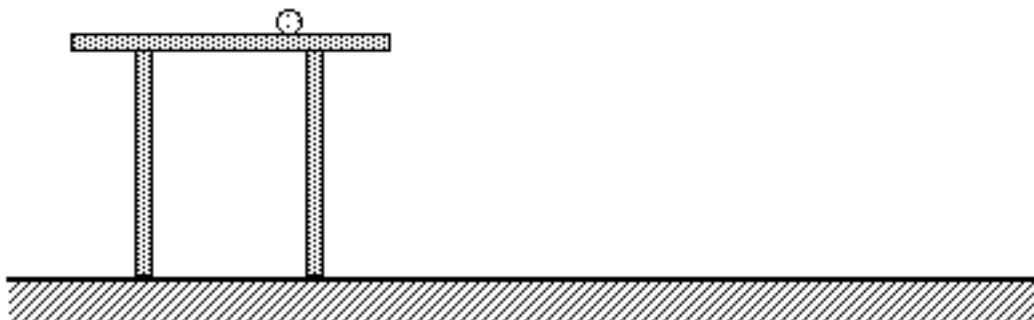


2. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two-story building at the same instant of time. Which ball will reach the ground first, or will they reach the ground at the same time? Explain your reasoning.

CHECK YOUR UNDERSTANDING

3. Suppose you throw a ball vertically up into the air with an initial velocity v_0 .
 - a. What is the acceleration of the ball at its maximum height? Explain your reasoning.
 - b. What would the acceleration-versus-time graph look like from the moment the ball leaves your hand to the moment before it returns to your hand?

4. A ball slides off the edge of a table with a horizontal velocity v_x and lands on the floor.



- a. On the diagram above, sketch a possible trajectory (the path followed by the ball) from the edge of the table to the floor.
- b. On the same diagram sketch another trajectory, that of another ball having a very much larger mass than that of the first ball, but exactly the same initial velocity v_x . Explain your reasoning.

TA Name: _____

PHYSICS 1101 LABORATORY REPORT

Laboratory II

Name and ID#: _____

Date performed: _____ Day/Time section meets: _____

Lab Partners' Names: _____

Problem # and Title: _____

Lab Instructor's Initials: _____

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL (incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

