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. Objects don't always move in a straight line. However, motion in two and three dimensions can be decomposed into a set of one-dimensional motions; what you learned in the first lab can be applied to this lab. You will also need to think of how air resistance could affect your results. Can it always be neglected? You will study the motion of an object in free fall, an object tossed into the air, and an object moving in a circle. 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.
- Determine the motion of an object moving in a circle from its horizontal and vertical components by considering what quantities and initial conditions affect the motion.

PREPARATION:

Read Paul M. Fishbane: Chapter 3. Review your results and procedures from Laboratory I. Before coming to the lab you should be able to:

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

After completing this laboratory see *Appendix E* (Sample Lab Report 1) for some suggestions on how to improve your lab reports.

PROBLEM #1:
MASS AND ACCELERATION OF A FALLING BALL

You have a job with the National Park Service. Your task is to investigate the effectiveness of spherical canisters filled with fire-retarding chemicals to help fight forest fires. The canisters would be dropped by low-flying planes or helicopters. They are specifically designed to split open when they hit the ground, showering the nearby flames with the chemicals. The canisters could contain different chemicals, so they will have different masses. In order to drop the canisters accurately, you need to know if the motion of a canister depends on its mass. You decide to model the situation by measuring the free-fall acceleration of balls with similar sizes but different masses.

EQUIPMENT

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

PREDICTION

Make a sketch of how you expect the *average acceleration vs. mass graph* to look for falling objects such as the balls in the problem.

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

WARM UP

Read: Fishbane Chapter 2, section 2.5.

Answering these questions will help you understand the implications of your prediction and interpret your experimental results.

1. Sketch a graph of *acceleration as a function of time* for a constant acceleration. Below it, make graphs for *velocity* and *position* as functions of time. Write down the equations that best represent each graph. If there are constants in each equation, what kinematics quantities do they represent? How would you determine these constants from your graphs?
2. Make two more sketches of the *acceleration vs. time graph*: one for a heavy falling ball and another for a falling ball with one quarter of the heavy one's mass. Explain your reasoning. Write the equation that best represents each of acceleration. If there are constants in your equations, what kinematics quantities do they represent? How would you determine the constants from your graphs? How do they differ from each other, and from your constant acceleration graph?

3. Use the relationships between acceleration and velocity and velocity and position of the ball to construct an *instantaneous velocity vs. time graph* and a *position vs. time graph* for each case from the previous question. The connection between the derivative of a function and the slope of its graph will be useful. Write down the equations that best represent each graph. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs? Can any of these constants be determined from the constants in the equations representing the acceleration and velocity?

4. Compare your graphs to those for constant acceleration. What are the differences, if any, that you might observe in your data? The similarities?

5. Write down an outline of how you will determine the acceleration of the object from video data.

6. Use the simulation "Lab2Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the approximate the 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* <x_0, y_0, z_0> *and* <v_{x0}, v_{y0}, v_{z0}>. *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 the ball's motion to fill 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 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 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. You also have the option of changing the camera settings.

Write down your measurement plan.

MEASUREMENT

Measure the mass of a ball and make a video of its fall according to the plan you devised in the exploration section.

Digitize the position of the ball in enough frames of the video so that you have the 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.

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. Don’t waste time in 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 for different balls.

ANALYSIS

Choose a function to represent the *position vs. time graph.* How can you estimate the values of the constants of the 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?

Choose a function to represent the *velocity vs. time graph.* How can you calculate the values of the constants of this function from the function representing the *position vs. time graph*? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent?

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?)

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 (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 graph this result. Do you have enough data to convince others of your conclusions about your predictions?

CONCLUSION

Did the data 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 not, what assumptions did you make that were incorrect? Explain your reasoning.

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

Do your results hold regardless of the masses of balls? Would the acceleration of a falling Styrofoam ball be the same as the acceleration of a falling baseball? Explain your rationale. Make sure you have some data to back up your claim. Will the acceleration of a falling canister depend on its mass? State your results in the most general terms supported by your analysis.

SIMULATION

If your results did not completely match your expectations, you should use the simulation “Lab2Sim” again (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.

EQUIPMENT

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

PREDICTION

Sketch a graph of a ball's acceleration as a function of time **after** it is launched in the manner described above. 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 changes? Make your best guess and explain your reasoning.*

WARM UP

Read: Fishbane Chapter 2, section 2.5.

The following questions will help you examine three possible scenarios. They should help you to understand your prediction and analyze your data.

1. How would you expect an *acceleration vs. time graph* to look for a ball moving downward with a constant acceleration? With a uniformly increasing acceleration? With a uniformly decreasing acceleration? Sketch the graph for each scenario and explain your reasoning. To make the comparison easier, draw these graphs next to each other. 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 kinematics 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 and velocity graphs?

3. Does your prediction agree with one of the scenarios you just explored? Explain why or why not.

4. Write down an outline of how you will determine the acceleration of the object from the video data.

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* $<x_0, y_0, z_0>$ *and* $<v_{x0}, v_{y0}, v_{z0}>$. *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. Repeat this procedure for different initial velocities.

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 for different launch velocities.

ANALYSIS

Choose a function to represent the *position vs. time graph.* How can you estimate the values of the constants of the 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?

Choose a function to represent the *velocity vs. time graph.* How can you calculate the values of the constants of this function from the function representing the *position vs. time graph*? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent? Determine the launch velocity of the ball from this graph. Is this value reasonable?

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?)

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?

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, use the simulation “Lab2Sim” again (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

A toy company has hired you to produce an instructional videotape for would-be jugglers. To plan the videotape, you decide to separately determine how the horizontal and vertical components of a ball's velocity change as it flies through the air. To catch the ball, a juggler must be able to predict its position, so you decide to calculate functions to represent the horizontal and vertical positions of a ball after it is tossed. To check your analysis, you decide to analyze a video of a ball thrown in a manner appropriate to juggling.

EQUIPMENT

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

PREDICTION

Note: for this problem, you should complete the Warm Up Questions to help formulate a prediction.

1. Write down equations to describe the horizontal and vertical velocity components of the ball as a function of time. Sketch a graph to represent each equation.

   *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** (does not change)? Make your best guess and explain your reasoning. What about the **vertical** component of its velocity?*

2. Write down the equations that describe the horizontal and vertical position of the ball as a function of time. Sketch a graph to represent each equation.

WARM UP

Read: Fishbane Chapter 3. Sections 3.1-3.4.

The following questions will help you calculate the details of your prediction and analyze your data.

1. Make a large (about one-half page) sketch of the trajectory of the ball on a coordinate system. Label the horizontal and vertical axes of your coordinate system.
2. On your sketch, draw acceleration vectors for the ball (show directions and relative magnitudes) at five different positions: two when the ball is going up, two when it is going down, and one at its maximum height. Explain your reasoning. Decompose each acceleration vector into its vertical and horizontal components.

3. On your sketch, draw velocity vectors for the ball at the same positions as your acceleration vectors (use a different color). Decompose each velocity vector into vertical and horizontal components. Check that the change of the velocity vector is consistent with the acceleration vector. Explain your reasoning.

4. *On your sketch*, how does the *horizontal* acceleration change with time? How does it compare to the gravitational acceleration? 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. *On your sketch*, how does the ball's horizontal velocity change with time? Is this 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. *Based on the equation of the ball's horizontal velocity*, 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?

7. *On your sketch*, how does the ball's vertical acceleration change with time? How does it compare to the gravitational acceleration? Write an equation giving the ball's vertical 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?

8. *On your sketch*, how does the ball's vertical velocity change with time? Is this consistent with your statements about the ball's acceleration questioning the previous question? Write an equation for the ball's vertical 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?

9. *Based on the equation describing the ball's vertical velocity*, write an equation for the ball's vertical 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?

10. 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 **after** it leaves your hand to reliably fill the video screen. Determine how much time it takes for the ball to travel and estimate the number of video points you will get in that time. Do you have enough points 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 need to place an object of known length on 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 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. Make sure you have enough useful frames for your analysis.

Digitize the position of the ball in enough frames of the video so that you have the 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.

ANALYSIS

Choose a function to represent the *horizontal position vs. time graph* and another for the *vertical position vs. time graph*. How can you estimate the values of the constants of the functions 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?

Choose a function to represent the *velocity vs. time graph* for each component of the velocity. How can you calculate the values of the constants of these functions from the functions representing the *position vs. time graphs*? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent? Determine the launch velocity of the ball from this graph. Is this value reasonable? Determine the velocity of the ball at its highest point. Is this value reasonable?

From the *velocity vs. time graphs* determine the acceleration of the ball independently for each component of the motion. Use the functions representing the *velocity vs. time graph* for each component to calculate each component of the ball's acceleration as a function of time. Is the acceleration constant from just after launch to just before the ball is caught? What is its direction? Determine the magnitude of the ball's acceleration at its highest point. Is this value reasonable?

CONCLUSION

Did your measurements agree with your initial predictions? Why or why not? Did your measurements agree with those taken by other groups? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

How do the horizontal components of a juggled ball's velocity and position depend on time? How do the vertical components of a juggled ball's velocity and position 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 shoud go back and use the simulation "Lab2Sim" again.

PROBLEM #4:
BOUNCING

You work for NASA designing a low-cost landing system for a Mars mission. The payload will be surrounded by padding and dropped onto the surface. When it reaches the surface, it will bounce. The height and the distance of the bounces will get smaller with each bounce so that it finally comes to rest on the surface. Your boss asks you to determine how the ratio of the horizontal distance covered by two successive bounces depends on the ratio of the heights of the two bounces and the ratio of the horizontal components of the initial velocity of the two bounces. After making the calculation you decide to check it in your laboratory on Earth.

EQUIPMENT

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

PREDICTION

Note: for this problem, you should complete the Warm up questions to help formulate a prediction.

Calculate the ratio asked for by your boss. (Assume that you know the ratio of the heights of the two bounces and the ratio of the horizontal components of the initial velocity for the two bounces.)

Be sure to state your assumptions so your boss can decide if they are reasonable for the Mars mission.

WARM UP

Read: Fishbane Chapter 3. Sections 3.1-3.4.

The following questions will help you make the prediction.

1. Draw a sketch of the situation, including velocity and acceleration vectors at all relevant times. Decide on a coordinate system. Define the positive and negative directions. During what time interval does the ball have motion that is easiest to calculate? Is the acceleration of the ball during that time interval constant or is it changing? Why? Are the time durations of two successive bounces equal? Why or why not? Label the horizontal distances and the maximum heights for each of the first two bounces. What reasonable assumptions will you probably need to make to solve this problem? How will you check these assumptions with your data?

2. Write down the basic kinematics equations that apply to the time intervals you selected, under the assumptions you have made. Clearly distinguish the equations describing horizontal motion from those describing vertical motion.

3. Write an equation for the horizontal distance the ball travels in the air during the first bounce, in terms of the initial horizontal velocity of the ball, its horizontal acceleration, and the time it stays in the air before reaching the ground again.

4. The equation you just wrote contains the time of flight, which must be re-written in terms of other quantities. Determine it from the vertical motion of the ball. First, select an equation that gives the ball's vertical position during a bounce as a function of its initial vertical velocity, its vertical acceleration, and the time elapsed since it last touched the ground.

5. The equation in the previous step involves two unknowns, which can both be related to the time of flight. How is the ball's vertical position when it touches the ground at the **end** of its first bounce related to its vertical position when it touched the ground at the **beginning** of its first bounce? Use this relationship and the equation from step 4 to write **one** equation involving the time of flight. How is the time of flight related to the time it takes for the ball to reach its maximum height for the bounce? Use this relationship and the equation from step 4 to write **another** equation involving the time of flight. Solve these two equations to get an equation expressing the time of flight as a function of the height of the bounce and the vertical acceleration.

6. Combine the previous steps to get an equation for the horizontal distance of a bounce in terms of the ball's horizontal velocity, the height of the bounce, and the ball's vertical acceleration.

7. Repeat the above process for the next bounce; take the ratio of horizontal distances to get your prediction equation.

8. Use the simulation "Lab2Sim" to simulate the lab as best as possible. You will need to trial different initial conditions and possibly use more frames than generally used.

EXPLORATION

Review your lab journal from any previous problem requiring analyzing a video of a falling ball.

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 bouncing the ball without spin until you can get at least two full bounces to fill the video screen. Three is better so you can check your results. It will take practice and skill to get a good set of bounces. Everyone in the group should try to determine who is best at throwing the ball.

Determine how much time it takes for the ball to have the number of bounces you will video 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 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 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 to your results. 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 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. Make sure you have enough frames to complete a useful analysis.

Digitize the position of the ball in enough frames of the video so that you have the 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.

ANALYSIS

Analyze the video to get the horizontal distance of two successive bounces, the height of the two bounces, and the horizontal components of the ball's velocity for each bounce. You may wish to calibrate the video independently for each bounce so you can begin your time as close as possible to when the ball leaves the ground. (Alternatively, you may wish to avoid repeating some work with the "Save Session" and "Open Session" commands.) The point where the bounce occurs will usually not correspond to a video frame taken by the camera so some estimation will be necessary to determine this position. (Can you use the "Save Data Table" command to help with this estimation?)

Choose a function to represent the *horizontal position vs. time graph* and another for the *vertical position graph* for the first bounce. How can you estimate the values of the constants of the functions? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent? How can you tell where the bounce occurred from each graph? Determine the height and horizontal distance for the first bounce.

Choose a function to represent the *velocity vs. time graph* for each component of the velocity for the first bounce. How can you calculate the values of the constants of these functions from the functions representing the *position vs. time graphs*? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent? How can you tell where the bounce occurred from each graph? Determine the initial horizontal velocity of the ball for the first bounce. What is the horizontal and vertical acceleration of the ball between bounces? Does this agree with your expectations?

Repeat this analysis for the second bounce, and the third bounce if possible.

What kinematics quantities are approximately the same for each bounce? How does that simplify your prediction equation?

CONCLUSION

How do your graphs compare to your predictions and warm up questions? What are the limitations on the accuracy of your measurements and analysis?

Will the ratio you calculated be the same on Mars as on Earth? Why?

What additional kinematic quantity, whose value you know, can be determined with the data you have taken to give you some indication of the precision of your measurement? How close is this quantity to its known value?

SIMULATION

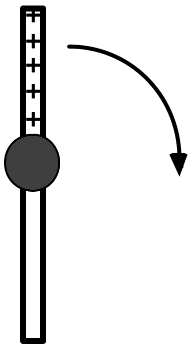
If your results did not completely match your expectations, you should again use the simulation "Lab2Sim" See *Appendix F* for a brief explanation of how to use the simulations, and see *Problem 2* in this laboratory for suggestions of how you could use the simulation here.

PROBLEM #5:
ACCELERATION AND CIRCULAR MOTION

You have been appointed to a Citizen Committee investigating the safety of a proposed new ride called "The Spinner" at the Mall of America's Camp Snoopy. The ride consists of seats mounted on each end of a steel beam. For most of the ride, the beam rotates about its center in a horizontal circle at a constant speed. Several Committee members insist that a person moving in a circle at constant speed is not accelerating, so there is no need to be concerned about the ride's safety. You disagree and sketch a diagram showing that each component of the velocity of a person on the ride changes as a function of time even though the speed is constant. Then you calculate the magnitude of a person's acceleration. The committee is still skeptical, so you build a model to show that your calculations are correct.

EQUIPMENT

You will be using an apparatus that spins a horizontal beam on A-frame base. A top view of the device is shown to the right. You will have a stopwatch, a meter stick and the video analysis equipment.



PREDICTION

Calculate the time dependence of the velocity components of an object moving like the ride's seats. Use this to calculate the object's acceleration.

WARM UP

Read: Fishbane Chapter 3, section 3.5.

The following questions will help with your prediction and data analysis.

1. Draw the trajectory of an object moving in a horizontal circle with a constant speed. Choose a convenient origin and coordinate axes. Draw the vector that represents the position of the object at some time when it is not along an axis.

2. Write an equation for one component of the position vector as a function of the radius of the circle and the angle the vector makes with one axis of your coordinate system. Calculate how that angle depends on time and the constant angular speed of the object moving in a circle (Hint: integrate both sides of equation 3-46 with respect to time). You now have an equation that gives a component of the position as a function of time. Repeat for the component perpendicular to the first component. Make a graph of each equation. If there are constants in the equations, what do they represent? How would you determine the constants from your graph?

3. From your equations for the components of the position of the object and the definition of velocity, use calculus to write an equation for each component of the object's velocity. Graph each equation. If there are constants in your equations, what do they represent? How would you determine these constants? Compare these graphs to those for the components of the object's position.

4. From your equations for the components of the object's velocity, calculate its speed. Does the speed change with time or is it constant?

5. From your equations for the components of the object's velocity and the definition of acceleration, use calculus to write down the equation for each component of the object's acceleration. Graph each equation. If there are constants in your equations, what do they represent? How would you determine these constants from your graphs? Compare these graphs to those for the components of the object's position.

6. From your equations for the components of the acceleration of the object, calculate the magnitude of the object's acceleration. Is it a function of time or is it constant?

EXPLORATION

Practice spinning the beam at different speeds. How many rotations does the beam make before it slows down appreciably? Use the stopwatch to determine which spin gives the closest approximation to constant speed. At that speed, how many video frames will you get for one rotation? Will this be enough to determine the characteristics of the motion?

Check to see if the spinning beam is level.

Move the apparatus to the floor and adjust the camera tripod so that the camera is directly above the middle of the spinning beam. Practice taking some videos. How will you make sure that you always click on the same position on the beam?

Decide how to calibrate your video.

MEASUREMENT

Acquire the position of a fixed point on the beam in enough frames of the video so that you have sufficient data to accomplish your analysis -- at least two complete rotations. 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 object travels and total time to determine the maximum and minimum value for each axis before taking data.

ANALYSIS

Analyze your video by digitizing a single point on the beam for at least two complete revolutions.

Choose a function to represent the graph of *horizontal position vs. time* and another for the graph of *vertical position vs. time.* How can you estimate the values of the constants in the functions? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent? Which are the same for both components? How can you tell from the graph when a complete rotation occurred?

Choose a function to represent the *velocity vs. time graph* for each component of the velocity. How can you calculate the values of the constants of these functions from the functions representing the position vs. time graphs? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent? Which are the same for both components? How can you tell when a complete rotation occurred from each graph?

Use the equations for the velocity components to calculate the speed of the object. Is the speed constant? How does it compare with your measurements using a stopwatch and meter stick?

Use the equations for the velocity components to calculate the equations that represent the components of the acceleration of the object. Use these components to calculate the magnitude of the total acceleration of the object as a function of time. Is the magnitude of the acceleration a constant? What is the relationship between the acceleration and the speed?

CONCLUSION

How do your graphs compare to your predictions and warm up questions? What are the limitations on the accuracy of your measurements and analysis?

Is it true that the velocity of the object changes with time while the speed remains constant?

Is the instantaneous speed of the object that you calculate from your measurements the same as its average speed that you measure with a stopwatch and meter stick?

Have you shown that an object moving in a circle with a constant speed is always accelerating? Explain.

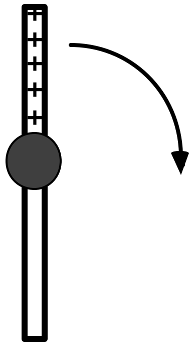
Compare the magnitude of the acceleration of the object that you calculate from your measurements to the “centripetal acceleration” that you can calculate from the speed and the radius of the object.

PROBLEM #6:
A VECTOR APPROACH TO CIRCULAR MOTION

You have a job supervising the construction of a highway. Safety requires that you know what the direction of a car's acceleration is when it moves at constant speed along curves. To check your prediction you decide to model, in the lab, curves that are arcs of circles.

EQUIPMENT

You will be using a apparatus that spins a horizontal beam on a A-frame base. A top view of the device is shown to the right. You will have a stopwatch, a meter stick and the video analysis equipment.



PREDICTION

What is the direction of the acceleration vector for an object moving at a constant speed along a circle's arc? Explain your reasoning.

WARM UP

Read: Fishbane Chapter 3, section 3.5.

The following questions will help you to make your prediction and analyze your data. These questions assume that you have completed the predictions and warm up questions for Problem 5. If you have not, you should do so before continuing.

1. Make a large (half-page) perpendicular coordinate system. Choose and label your axes. Draw the trajectory of the object moving along a circular road on this coordinate system. Show the positions of your object at equal time intervals around the circle. Choose several points along the trajectory (at least one per quadrant of the circle) and draw the position vector to each of these points. Write down the equations that describe the components of the object's position at each point.

2. From your position equations, calculate the components of the object's velocity at each point. Choose a scale that allows you to draw these components at each point. Add these components (as vectors) to draw the velocity vector at each point. What is the relationship between the velocity vector direction and the direction of the radial vector from the center of the circle?
3. From your velocity equations, calculate the components of the object's acceleration at each point. Choose a scale that allows you to draw these components at each point. Add these components (as vectors) to draw the acceleration vector at each point. What is the relationship between the acceleration vector direction and the radius of the circle?

EXPLORATION

If you have already done Problem 5, you can use that video and move on to the analysis. If not, do the exploration for that Problem.

MEASUREMENT

If you have already done Problem 5, you can use those measurements and move on to the analysis. If not, do the measurement for that Problem.

ANALYSIS

Analyze your video to get equations that describe the motion of a point going in a circle at constant speed. You can use the equations for position and velocity components you found for Problem 5.

Use the procedure outlined in the Warm Up Questions to analyze your data to get the direction of the acceleration of the object in each quadrant of the circle.

CONCLUSION

How does the direction of the acceleration compare to your prediction? What are the limitations of your measurements and analysis?

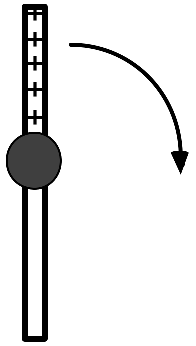
What is the direction of the acceleration for a car moving with a constant speed along a curve that forms an arc of a circle? State your result in the most general terms supported by your analysis.

PROBLEM #7:
ACCELERATION AND ORBITS

You work with a research group investigating the possibility of extraterrestrial life. Your team is looking at the properties of newly discovered planets orbiting other stars. You have been assigned the task of determining the gravitational force between planets and stars. As a first step, you decide to calculate a planet's acceleration as a function of its orbital radius and period. You assume that it moves in a circle at a constant speed around the star. From previous measurements, you know the radius and period of the orbit.

EQUIPMENT

You will be using a apparatus that spins a horizontal beam on a A-frame base. A top view of the device is shown to the right. You will have a stopwatch, a meter stick and the video analysis equipment.



PREDICTION

Calculate the acceleration of an object moving as the planet that you are investigating. Make two graphs with one showing acceleration as a function of radius (for a fixed period) and another showing acceleration as a function of period (for a fixed radius.)

WARM UP

Read: Fishbane Chapter 3, section 3.5.

The following questions should help with the prediction. In addition, do the Warm up questions for Problem 5 if you have not already done them.

1. Draw the trajectory of an object moving in a circle when its speed is not changing. Draw vectors describing the kinematic quantities of the object. Label the radius of the circle and the relevant kinematic quantities. Choose and label your coordinate axes.
2. Write down the kinematic equations that describe this type of motion. Your equations should include the definition of speed when the speed is constant and the relationship between acceleration and speed for uniform circular motion. You are now ready to plan your mathematical solution.

3. Select an equation identified in step 2, which gives the acceleration in terms of quantities you "know" and additional unknowns. In this problem, you know the radius and the period of the object's motion.
4. If you have additional unknowns, determine one of them by selecting a new equation, identified in step 2, relating that unknown to other quantities. Repeat this step until you have no additional unknowns.

EXPLORATION

If you have already done Problem 5, you can use that video for some of your data. If not, do the exploration given in that Problem.

Decide how you can measure objects at several different positions on the beam while holding the period of rotation constant. How many videos do you need to take for this measurement? Decide how you can measure objects at the same position on the beam for different periods of rotation. How many videos do you need to take for this measurement?

MEASUREMENT

Use your plan from the Exploration section to make your measurements.

If you have already done Problem 5, you can use that for one of your measurements. If not, do the measurement as given in that Problem. In addition, make several measurements at different radii and different periods in a range that will give your predictions the most stringent test.

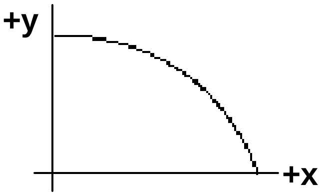
ANALYSIS

Use your technique from Problem 5 to analyze your video for the magnitude of the acceleration that describes the motion of a point going in a circle at constant speed. You can also determine the radius of the object and its period from this data. Make a graph of acceleration as a function of radius for objects with the same period. Make a graph of acceleration as a function of period for objects with the same radius.

CONCLUSION

Are your measurements consistent with your predictions? Why or why not? What are the limitations 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.

a. Which graph below best represents the *horizontal position (x) vs. time* graph? Explain your reasoning.

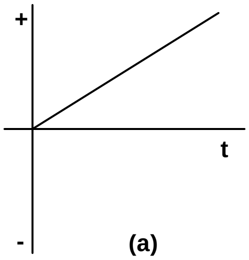
b. Which graph below best represents the *horizontal velocity (v_x) vs. time* graph? Explain your reasoning.

c. Which graph below best represents the *horizontal acceleration (a_x) vs. time* graph? Explain your reasoning.

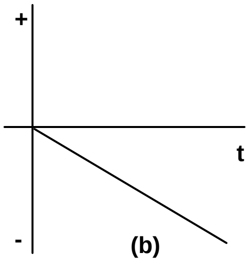
d. Which graph below best represents the *vertical position (y) vs. time* graph? Explain your reasoning.

e. Which graph below best represents the *vertical velocity (v_y) vs. time* graph? Explain your reasoning.

f. Which graph below best represents the *vertical acceleration (a_y) vs. time* graph? Explain your reasoning.



(a)



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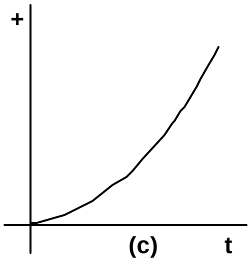

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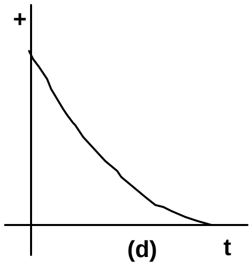

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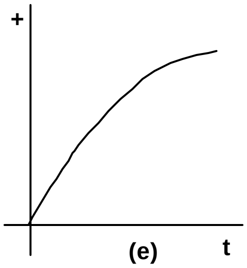

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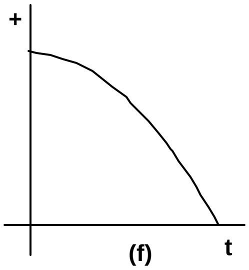
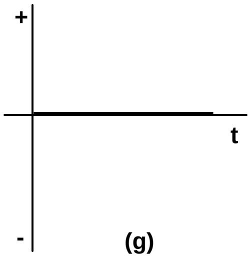
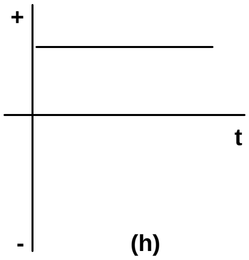


(f)



(g)



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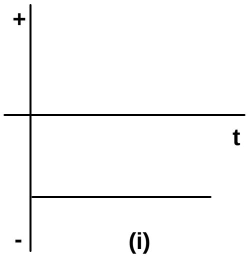


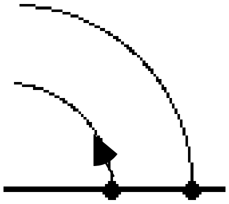
(i)

☑ CHECK YOUR UNDERSTANDING

2. Suppose you throw a ball vertically up into the air with an initial velocity v_o.

   a. What is the acceleration of the ball at its maximum height? Explain your reasoning.

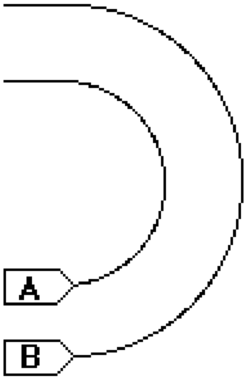
   b. How would the acceleration vs. time graph look from the moment the ball leaves your hand to the moment before it returns to your hand?



3. Two beads are fixed to a rod rotating at constant speed about a pivot at its left end, as shown in the drawing at right.

   a. Which bead has the greater speed? Explain your reasoning.

   b. Which bead has the greater acceleration? Explain your reasoning.



4. Two racing boats go around a semicircular turn in a racecourse. The boats have the same speed, but boat A is on the inside while boat B is on the outside, as shown in the drawing.

   a. Which boat gets around the turn in the smaller time? Explain your reasoning.

   b. Which boat undergoes the greater change in velocity while in the turn? Explain your reasoning.

   c. Based on the definition of acceleration, which boat has the greater acceleration while in the turn? Explain your reasoning.

   d. Based on the equation for centripetal acceleration, which boat has the greater acceleration while in the turn? Compare your answer to part c. Explain your reasoning.

TA Name:______________________________

PHYSICS 1301 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.