LABORATORY II
FORCE AND CONSERVATION OF ENERGY

After studying forces and material bodies in equilibrium, it is natural to examine how forces may affect bodies when they move. We will also explore the relationship between forces and energy conservation. Energy and forces, together, support an extremely versatile and powerful set of tools for solving physics problems.

OBJECTIVES:

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

- Use the concept of energy to solve problems.

- Make quantitative predictions about the relationship of forces on objects and the motion of those objects and test these predictions for real systems.

PREPARATION:

Read Serway & Jewett chapter 2 (sections 1-3), and chapter 6. It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. It is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

- State the principle of conservation of energy; state the relationship between the work done on an object and its kinetic energy.

- Define and use sine, cosine and tangent for a right triangle.

- Recognize the difference between mass and weight.

- Define, use, and know the difference between average velocity and velocity.

- Draw and use force diagrams.

- Write down the empirical force law for a frictional force.

PROBLEM #1:
CONSTANT VELOCITY MOTION

You are working in a research lab that uses gel phase electrophoresis for separating protein molecules by mass. In this process the molecules move slowly across the substrate. You have been asked to measure their velocity. One technique to get the velocity is to measure the time the protein takes to travel a measured distance. To determine if this is valid, you decide to videotape the protein motion and analyze the video. You will then compare the video analysis to the distance and time measurement. To develop your technique, you decide to practice using a cart as the moving object. You decide to give the cart a push so that it moves down a horizontal track and make a video of its motion. You then compare your video analysis for velocity to a distance and time measurement using a stopwatch and a meter stick. Your video analysis can generate position-vs.-time from them velocity-vs.-time graphs. Before you do your first video you predict the result by sketching a graph of what you think the position-vs-time graph will be for the cart and then use that graph to make a velocity-vs-time graph. Show how your graphical results would compare to a velocity calculated by using the total distance and total time from the first graph.

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EQUIPMENT

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For this problem, you will use a PASCO cart and an aluminum track. 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, described in *Appendix D*). Each frame of the video shows you the object's position at the time that than frame was recorded.
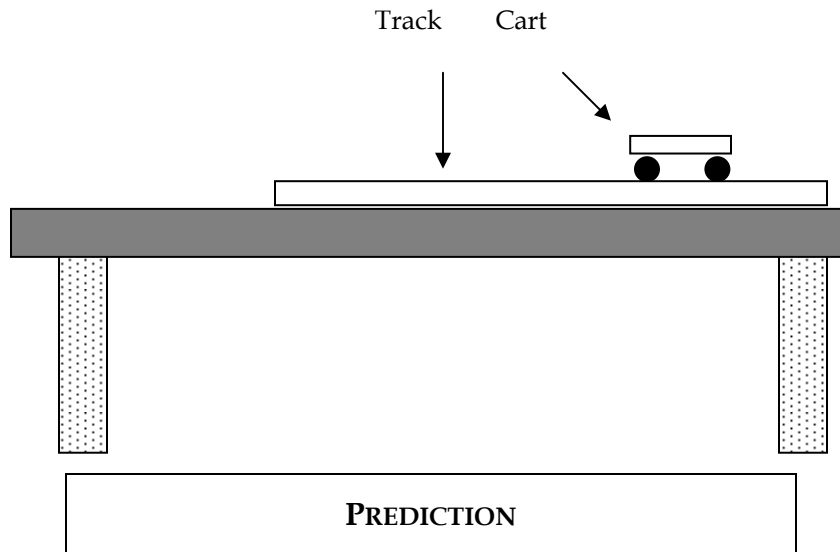
Track   Cart

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PREDICTION

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Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What do you wish to be able to determine about the motion of the cart? How will the data available (position-vs.-time and velocity-vs.-time graphs) allow you to determine this? Sketch the position-vs-time graph and explain why it should have this shape. Sketch the velocity-vs-time graph and explain its shape.

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

To make your prediction, you need to think about how to measure and represent the motion of an object. The following questions should help with the analysis of your data.

Read: Serway and Jewett Chapter 2 sections 1, 2, and 3

1. How would you expect an *instantaneous velocity vs. time* graph to look for an object with constant velocity? Make a rough sketch and explain your reasoning. Assign appropriate labels and units to your axes. Write an equation that describes this graph. What is the meaning of each quantity in your equation? How does each quantity in your equation show up on your graph?

2. How would you expect a *position vs. time* graph to look for an object moving with constant velocity? Make a rough sketch and explain your reasoning. What is the relationship between this graph and the instantaneous velocity versus time graph? Write down an equation that describes this graph. What is the meaning of each quantity in your equation? How does each quantity in your equation show up on your graph? In terms of the quantities in your equation, what is the velocity?

3. Repeat the first two steps if the cart is slowing down slightly as it moves down the track.

4. Repeat the first two steps if the cart is speeding up slightly as it moves down the track.

5. Use the simulation "Lab1Sim" to model constant velocity motion of the protein molecule or the cart you will be using instead of the molecule. You will need to experiment with the settings to find conditions that will produce a constant velocity motion. (See *Appendix F* for an introduction to the Simulation Programs.) The simulations allow you to create real time graphs that will help you understand the relationships between velocity/position/acceleration and time. You should note that the graphs aren't labeled. Produce simulated *position vs. time* and *velocity vs. time* graphs of constant velocity motion, and verify that they meet your expectations. Add a small amount of uncertainty to the position measurements by pressing "Add Error" in the "Graph frame." Note the effect of error in the *position vs. time* graph and in the *velocity vs. time* graph.

EXPLORATION

Place one of the metal tracks on your lab bench and place the cart on the track. Give it a push and observe its motion. Does it appear to move with a constant velocity? Use the meter stick and stopwatch to determine the average speed of the cart. Try pushing the cart so that it has the same velocity each time you push it. Estimate how consistent its velocity can be.

Turn on the video camera and look at the motion as seen by the camera on the computer screen. Refer to *Appendix D* for instructions about using the VideoRECORDER software.

Do you need to focus the camera to get a clean image? How do the room lights affect the image? Which controls help sharpen the image? Record your camera adjustments in your lab journal.

Move the position of the camera closer to the cart. How does this affect the video image on the screen? Try moving it farther away. Raise the height of the camera tripod. How does this affect the image? Decide where you want to place the camera to get the most useful image.

Practice taking videos of the cart. You will make and analyze many videos in this course! Write down the best situation for taking a video in your journal for future reference. When you have the best movie possible, save it in the My Documents folder.

What would happen if you calibrate using an object that is closer to your camera than the object of interest?

What would happen if you click on a different part of the moving object to get your different data points?

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MEASUREMENT

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Record the time the cart takes to travel a known distance. Estimate the uncertainty in time and distance measurements. Take a good video of the cart's motion. Analyze the video with VideoTOOL to predict and fit functions for *position vs. time* and *velocity vs. time*.

Quit VideoRECORDER and open VideoTOOL to analyze your movie.

Although the directions to analyze a video are given during the procedure in a box with the title "INSTRUCTIONS", the following is a short summary of them that will be useful to do the exploration for this and any other lab video (for more information you should read *Appendix D*).

Warning: Be very careful in following these steps, if you make a mistake you may not be able to go backwards; you might need to restart from the first step.

1. To open your video click the "Open Video" button.

2. Select "Begin calibration" and advance the video with the "Step >" button to the frame where the first data point will be taken. This step sets up the origin of your time axis (t=0).

3. To tell the analysis program the real size of the video images, select some object in the plane of motion that you can measure. Drag the green cursor, located in the top left corner of the video display, to one end of the calibration object. Click the "x0, y0" button when the green cursor is in place. Move the green cursor to the other end and select "x1, y1". Enter the length of the object in the "Length" box and specify the "Units". Select the "OK" button twice to complete the calibration sequence.

4. Enter your prediction equations of how you expect the position of the object to change with time. Notice that the symbols used by the equations in the program are *general letters*, which means that you have to identify those with the quantities involved in your prediction. In order to make the best guess you will need to take into account the scale and the values from your practice trials using the stopwatch and the meter stick. Once your x-position prediction is ready, select "Accept x–prediction" and repeat the previous procedure for the y-position.

5. To start your data collection, click the "Acquire data" button. Select a specific point on the object whose motion you are analyzing. Drag the green cursor over this point and click the "Accept Data Point" button and you will see the data on the appropriate graph on your computer screen, after this the video will advance one frame. If you do not see your data point on the graph, change the scale of the graph axes. Again drag the green cursor over the same point selected on the object and accept the data point. Keep doing this until you have enough data.

6. Click the "Analyze Data" button and fit your data. Decide which equation and parameters are the best approximations for your data and accept your "x-fit" and "y-fit". To do this you will probably have to adjust the scale of your axes so that you can see the behavior of the data. If the scale is too large, you will not be able to see important changes in behavior. If the scale is too small the data will be so "jumpy" that you will not be able to see the overall behavior.

7. Next the program will ask you to enter your prediction for velocity in the x- and y-direction. Choose the appropriate equations and give your best approximations for the parameters. The parameters for the position equations will help you determine these parameters. Accept your v_x- and v_y-predictions and you will see the data on the last two graphs.   Again you will probably need to adjust the scale of each axis.

8. Fit your data for these velocities in the same way that you did for position. Accept your fit and click the "Print Results" button to view a PDF document of your graphs that can be e-mailed to you and your group members.

If possible, every member of your group should analyze a video. Record your procedures, measurements, prediction equations, and fit equations in a neat and organized manner

Note: Be sure to record your measurements with the appropriate number of significant figures and with your estimated uncertainty (see Appendix B).

ANALYSIS

Calculate the average speed of the cart from your stopwatch and meter stick measurements. Can you determine the instantaneous speed of your cart as a function of time from these measurements? If so how?

Analyze your video to find the instantaneous speed of the cart as a function of time. Determine if the speed is constant within your measurement uncertainties.

When you have finished making a fit equation for each graph, rewrite the equations in your lab journal the *general letters* to those appropriate for the *kinematic quantities* they represent. Make sure all quantities are assigned the correct units.

CONCLUSION

Compare the cart's speed measured with video analysis to the measurement using a stopwatch. How do they compare? Did your measurements and graphs agree with your answers to the Warm-up

Questions?   If not, why?   What are the limitations on the accuracy of your measurements and analysis? Are the techniques used in this lab problem applicable to analyzing the motion of protein molecules moving through gel? How is the motion of protein molecules similar to the motion of the cart? How would it differ?

SIMULATION

Compare the simulated graphs to your graphs of the car's motion. If your graphs did not perfectly represent what you expect for constant velocity motion, use the simulation "Lab1Sim" (See *Appendix F* for an introduction to the Simulation Programs) to see the effects of uncertainty in position measurement. Can you more easily see the effect in the *position vs. time* graph or in the *velocity vs. time* graph?

In VideoTOOL and "Lab1Sim", how do you think the computer generates data for a velocity graph? How is this related to the effect of measurement uncertainty on velocity (compared to position) graphs? Why is there one less data point in a *velocity vs. time* graph than in the corresponding *position vs. time* graph?

A computer simulation of the motion will also let you determine how parts of the experiment outside your control in the real world could affect your results. For example, you can adjust friction or air resistance to see what role they play in the results.

PROBLEM #2:
FALLING

While watching a cat you wonder about its biomechanics. It seems that a cat lands easily after jumping from heights that would injure a human. This puzzles you because you know that a human has much stronger bones and muscles than a cat. On of your friends believes that the answer is simple, humans are heavier than cats and therefore fall faster. When a human and a cat fall from the same height, the human hits the ground going much faster and sustains more injury. You are not so sure that this is the explanation so you calculate the speed that an object hits the ground as a function of its height and its mass using conservation of energy. Because both the human subjects committee and animal rights groups would object if you tested this idea by pushing your friend and a cat off a building, you decide to measure the speed of falling balls with different masses dropped from the same height in the laboratory.

EQUIPMENT

For this problem, you will have a collection of balls with approximately the same size 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

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. From your equation, draw a velocity-vs-time graph and a position-vs-time graph. Explain how these graphs resulted from your equation.

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 2.2, 4.5, 6.1, 6.2, 6.5, and 6.6.

1. Draw a diagram of a ball in midair and establish a convenient coordinate system. Identify all the forces acting on the ball. State any simplifying assumptions you make.

2. Does the ball fall with a constant speed or is it speeding up or slowing down? Sketch a graph of how you think the ball's *velocity* changes with *time*. What is the shape of the graph and what features of that shape correspond to physical quantities that you know? How does the speed of the ball just after you release it show up on the graph? Make a *position vs. time* graph based on your *velocity vs. time* graph? How do the features of the *velocity vs time* graph show up on the *position vs. time* graph? Calculus is very useful for this discussion

3. Write an equation for the ball's kinetic energy in terms of its velocity. Identify all forces on the ball that cause either an energy input to the ball or an energy output from the ball. Write an equation that relates this energy transfer to these forces. Use conservation of energy to relate the kinetic energy of a ball to this energy transfer. Use this result to get an equation for velocity in terms of the forces acting on the ball. How does it depend on mass? Is this solution consistent with your qualitative solution?

4. Use your conservation of energy equation and calculus to write an expression for the ball's position as a function of time. Make a graph of this equation and compare it to the graph you sketched in 2.

5. Use your equation for position as a function of time and calculus to write an equation for the ball's velocity as a function of time. Make a graph of this equation and compare it to the graph you sketched in 2.

6. Use the simulation "Lab2Sim" to explore the approximate the conditions of your experiment. (See Appendix F for a brief explanation of how to use the simulations.) If you believe friction or air resistance may affect your results, explore the effects of each with the simulation. If you believe that uncertainty in position measurements may affect your results, use the simulation to compare the results with and without error. Take note of the effect of error on the various graphs. Remember to check for the effects of measurement uncertainty in your VideoTOOL measurements later in lab.

EXPLORATION

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 and screen size to give you enough data points. Take a test video and step through it to determine its quality.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. If your image is not sharp or not bright enough to determine the edges of the ball, ask your instructor to adjust its shutter speed or sensitivity. If this adjustment cannot be made, and you cannot clearly determine the edges of your ball in the first frame of the video you want to use, you can 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.

Step through the video and determine which part of the ball is easiest to consistently mark. When the ball moves rapidly the image may blur because of the shutter speed of the camera. It is also possible that the image is too dark or too light to see a good edge.

Measure the distance the ball travels with a meter stick and the time for the fall to determine the maximum value for each axis (as well as to check that the numbers the computer will give you make sense) before taking data. Try balls of different mass.

Does the size of the ball really make a difference? If they are available, try balls of different size. What origin of the coordinate system will you use for the graph? Check whether up or down is

positive. If the camera is slightly tilted, how will that affect your measurement? Write down your measurement plan.

MEASUREMENT

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

Measure 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.

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. (Refer to the Exploration section in Problem 1 for instructions on using the software, and Appendix D "Video Analysis of Motion" as necessary.) Don't waste time in collecting data you don't need or, even worse, collecting 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*. Estimate the values of the parameters of the function from the points on the graph. Use the concepts of calculus. You can waste a lot of time if you just try to guess the constants. What kinematics quantities do these parameters represent?

Choose a function to represent the *velocity vs.time* graph. Calculate the values of the parameters of this function from the function representing the *position vs. time* graph using calculus. Check how well this works. You can also estimate the values of the parameters from the graph itself. Just trying to guess the constants can waste a lot of your time. What kinematics quantities do these parameters represent?

Use the fit equations for *position vs. time* and *velocity vs. time* to determine a single equation for *velocity* as a function of *position*.

Compare the information contained in the graphs of balls with different masses.

CONCLUSION

What do your measurements say about the variation of the velocity of a free-falling object with time? What do your measurements say about the variation of velocity with the height at which the object is dropped? Did the data support your predictions? If not, what assumptions did you make that were incorrect? Explain your reasoning.

Does the ball's velocity change more or less in the first centimeter of falling or the last centimeter? Support your answer with your data, and with physics reasoning.

Do your results hold regardless of the mass of the ball? Would the character of the motion of a falling Styrofoam ball be the same as that of a falling baseball? Do the size and shape of the object matter? Is air resistance significant?

Will the velocity of a falling cat be larger or smaller than that of a person who has fallen the same distance? State your results in the most general terms supported by your analysis. Compare the kinetic energy of a cat and that of a person just before each strikes the ground. What is the effect of this energy when each makes a hard landing?

SIMULATION
Compare the simulated graphs to your graphs of the falling objects. If your results did not completely match your expectations, use the simulation "Lab2Sim" to explore what might have happened (See *Appendix F* for a brief explanation of how to use the simulations). First, set the simulation to approximate the conditions of your experiment. Can you get the behavior, and the graphs of position and velocity, that you expect?

Discuss the graphs produced by the simulation and verify that they meet your expectations. Use the simulation controls to vary the amount of air resistance and the mass of the object. Can you more easily see the effects in the *position vs. time* graph or in the *velocity vs. time* graph? Use the simulation to determine how your uncertainties affect your measurements.

PROBLEM #3:
MOTION DOWN AN INCLINE

You are part of a group concerned about injuries to children. One common injury is the result of skateboard accidents. Skateboarders typically pick up speed by going down some kind of ramp. The faster the skateboard goes, the more serious the potential injury. To study different safety devices, you first need to determine how the speed of a skateboard depends on the characteristics of a ramp. For this reason you decide to calculate the final speed of a skateboard coming off a ramp as a function of the properties of the ramp and the mass of the skateboard. You will then test your calculation in the laboratory using a cart going down a sloped track.

EQUIPMENT
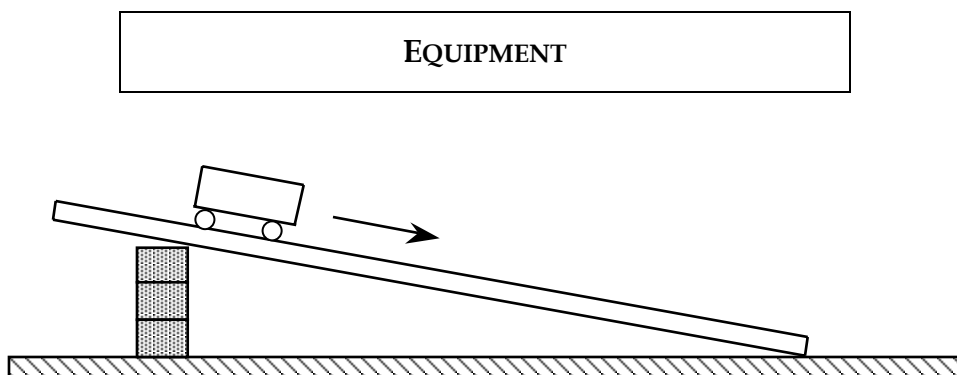
For this problem you will have a PASCO cart, an aluminum track with an end stop, a stopwatch, a meter stick, blocks, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 1.10, 2.2, 4.5, 4.6, 6.1, 6.2, 6.5, and 6.6.

1. Draw a picture of the situation labeling all of the relevant forces, distances, and angles. Decide on a useful coordinate system and explain why you chose it. Draw a free-body diagram of the cart as it moves down the track. Show all forces acting on the cart. Describe which forces you can neglect and explain why.

2. Draw your coordinate system and put the forces on the cart on it. Is there a component of the cart's motion that can be considered as in equilibrium in your coordinate system?

3. Write down the forces or force components that transfer energy to or from the cart. If any angles are involved, write down how they are related to the angle of the track.

4. Calculate the energy transferred to the cart and the energy transferred from the cart. Relate this energy transfer to the change of the kinetic energy of the cart.

5. From this conservation of energy equation use calculus to get an equation describing how the position of the cart changes with time. Use this equation and calculus to get another equation describing how the velocity of the cart changes with time.

6. Use the simulation "Lab1Sim" to explore the approximate the conditions of your experiment. (See Appendix F for a brief explanation of how to use the simulations.) If you believe friction or air resistance may affect your results, explore the effects of each with the simulation. If you believe that uncertainty in position measurements may affect your results, use the simulation to compare the results with and without error. Take note of the effect of error on the various graphs. Remember to check for the effects of measurement uncertainty in your VideoTOOL measurements later in lab.

EXPLORATION

What is the best way to change the angle of the incline in a reproducible way? How can you use trigonometry to measure this angle with respect to the table?

Start with a small angle and with the cart at rest near the top of the track. Observe the cart as it moves down the inclined track. Explore a range of angles and roughly measure the time it takes to get to the bottom. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP!** If the time is too short, you may not get enough video frames, and thus enough position and time measurements. If the time is too long, you may not be able to neglect certain forces. Select the best angle for this measurement.

Where is the best place to put the camera? Which part of the motion do you wish to capture? Explore different camera positions.   Should you rotate your coordinates? If so how? What will you use as your calibration object?

Where is the best place to release the cart so it does not damage the equipment but has enough of its motion captured on video? Be sure to catch the cart before it collides with the end stop. Take a few practice videos and play them back to make sure you have captured the motion you want.

What is the total distance through which the cart rolls? How much time does it take? These measurements will help you set up the graphs for your computer data taking.

See qualitatively how the motion changes when you change the mass of the cart by the maximum amount. How many different cart masses to you need to determine the effect of the mass of the cart on the final velocity?

You may wish to follow the steps given in the "Exploration" section of problem 1 to work with your video.

Write down your measurement plan.

MEASUREMENT

Follow the measurement plan you wrote down.

When you have finished making measurements, you should e-mail PDF files of the position and velocity graphs to each group member. Sketch the graphs in your lab journal, and check that you have kept good records of your determination of the incline angle, the time it takes the cart to roll a known distance down the incline starting from rest, the length of the cart, the length of the track, and prediction and fit equations for position and velocity. All of the preceding measurements should include your estimate of the measurement uncertainties.

Make sure that every one gets the chance to operate the computer.
Record all of your measurements; you may be able to re-use some of them in other lab problems.

ANALYSIS

Choose a function to represent the *position vs. time* graph. Write down the physical meaning of each parameter in the equation. Use your knowledge of functions and calculus to estimate the values of the constants of the function from the graph itself and the measurements you made in the exploration section. You can waste a lot of time if you just try to guess the constants.

Choose a function to represent the *velocity vs. time* graph. 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 itself. Just trying to guess the constants can waste a lot of your time. What kinematics quantities do these constants represent?

Combine your equation for position as a function of time and your equation of velocity as a function of time to arrive at an equation of velocity as a function of position.

For each different angle, you should do the above analysis once.

CONCLUSION

How do the graphs of your measurements compare to your predictions? How does velocity vary with the distance the cart travels and the angle of the incline? In what sense is the motion similar to freefall? In what sense is it different? Extrapolate your results to the case of a vertically inclined track and compare with that of freefall.

In what direction is the cart accelerating? How does the downward component of that acceleration compare with the gravitational acceleration of the cart if you dropped it?

SIMULATION

If your results did not completely match your expectations, you may use the simulation "Lab1Sim" to explore what might have happened (See *Appendix F* for a brief explanation of how to use the simulations). First, set the simulation to approximate the conditions of your experiment. Can you get the behavior, and the graphs of position and velocity, that you expect?

Address (or re-address if you have already considered them) the following questions. In VideoTOOL and "Lab1Sim", how do you think the computer generates data for a velocity graph? How is this related to the effect of measurement uncertainty on velocity (compared to position) graphs? Why is there one less data point in a *velocity vs. time* graph than in the corresponding *position vs. time* graph?

Investigate the effect of friction or air resistance by changing these settings in the simulation. How does increasing the friction affect the *velocity vs. time* graph? Can you tell the difference between this effect and the effect due to uncertainty? Do you see a friction effect in your data?

Examine the effect of changing the gravitational acceleration in the simulation.
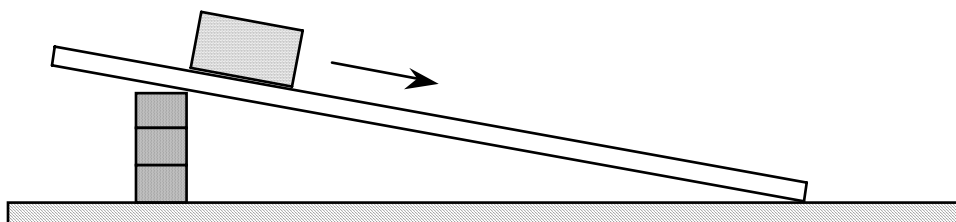
PROBLEM #4:
NORMAL FORCE AND FRICTIONAL FORCE

You are working in a biotech company investigating substances that organisms produce to cope with their environment. Some of these substances could be synthesized and be useful to humans. For example, some fish have a substance on their scales that reduces the friction between them and the water. This substance might be a replacement for oil based lubricants in some types of machinery. To test the effectiveness of such substances, you decide to measure its coefficient of kinetic friction when used between an object moving down a ramp and the ramp.

First you need to determine how well the approximate expression relating the frictional force to the normal force and the coefficient of kinetic friction works under laboratory conditions. To perform this check you decide to calculate the frictional force when a block of wood slides down an aluminum ramp using conservation of energy. Then you calculate the normal force using Newton's second law. Assuming the usual expression for the frictional force is approximately correct in this situation you make a sketch of the graph that should result from plotting frictional force determined by conservation of energy versus normal force determined by Newton's second law. This is what you will test in the laboratory.

EQUIPMENT

For this problem you will have an aluminum track, a stopwatch, a meter stick, a balance, wood blocks, weights, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTIONS

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get the two equations that each give one of the forces you need to solve the problem. Make sure that you state any approximations or assumptions that you are making. Make sure that in each case the force is given in terms of quantities you know or can measure. Write down the approximate expression for friction that you are testing and sketch a graph of frictional force as a function of normal force for that equation.

What assumptions are you making to solve this problem?

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WARM-UP QUESTIONS

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Read Serway & Jewett: sections 1.10, 2.2, 4.5, 4.6, 5.1, 6.1, 6.2, 6.5, and 6.6.

1. Make a drawing of the problem situation including labeled vectors to represent the motion of the block as well as the forces on it. What measurements can you make with a meter stick to determine the angle of the incline?

2. Draw a free-body diagram of the block as it slides down the track. Choose a coordinate system that will make calculations of energy transfer to and from the block easiest. What is your reason for choosing that coordinate system?

3. Transfer the force vectors to your coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the track and the table?

4. In the coordinate system you have chosen, is there a component of the block's motion that can be considered as in equilibrium? Use Newton's second law in that direction to get an equation for the normal force in terms of quantities you know or can measure. Does the normal force increase, decrease, or stay the same as the ramp angle increases?

5. Write down the energy transfer to or from the block caused by each of the forces acting on the block when the block has slid some distance. Which forces give an energy input and which an output? Write down an equation that expresses conservation of energy for this situation. Solve this equation for the kinetic frictional force.

6. Sketch a graph of the frictional force as a function of the normal force if the approximate relationship between them is good in this situation. How would you determine the coefficient of kinetic friction from this graph?

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EXPLORATION

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The frictional force is usually very complicated but you need to find a range of situations where its behavior is simple. To do this, try different angles until you find one for which the wooden block slides smoothly down the aluminum track every time you try it. Make sure this is also true for the range of weights you will add to the wooden block.

You can change the normal force on the block either by changing the weight of the block and keeping the angle of the track the same or by changing the angle of the track and keeping the weight of the block the same.

Select an angle and determine a series of masses that always give you smooth sliding. Select a block mass and determine a series of track angles that always give you smooth sliding. Determine which procedure will give you the largest range of normal forces for your measurement.

Write down your measurement plan.

<div style="border:1px solid black; text-align:center;">

MEASUREMENT

</div>

Follow your measurement plan. *Make sure you measure and record the angles and weights that you use.*

Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the wooden block depends on the normal force on the wooden block.

<div style="border:1px solid black; text-align:center;">

ANALYSIS

</div>

From your video analysis and other measurements, calculate the magnitude of the kinetic frictional force. Also determine the normal force on the block.

Graph the magnitude of the kinetic frictional force against the magnitude of the normal force. On the same graph, show the relationship predicted by the approximation for kinetic friction.

<div style="border:1px solid black; text-align:center;">

CONCLUSION

</div>

Is the approximation that kinetic frictional force is proportional to the normal force useful for the situation you measured? Justify your conclusion. What is the coefficient of kinetic friction for wood on aluminum? How does this compare to values you can look up in a table such as the one is given at the end of this lab?

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph match the predicted graph best? Where do the two curves start to diverge from one another? What does this tell you?

PROBLEM #5:
VELOCITY AND FORCE

You are in a research group investigating whether birds are the direct descendants of dinosaurs. Of particular interest are the most primitive gliding dinosaurs. Your team will build models of these animals with different wing shapes to study the difficulties in becoming airborne. You are assigned to design a simple launch mechanism that will provide a reproducible launch velocity. In your design, the dinosaur model will ride on a cart that moves along a horizontal track. The cart begins its motion when the hanging object attached to it by rope going over a pulley is allowed to fall. You need to calculate the speed of the cart as a function of the mass of the hanging object, the mass of the cart, and the distance that the hanging object falls. You will then test your calculations in the laboratory. One of your colleagues claims that the calculation is easy because the force of the string on the cart is just the weight of the hanging object. Another colleague claims that the calculation is even easier if you calculate the velocity of the cart as a function of time. Then the velocity of the cart that you want is just the distance the hanging object falls divided by the time it takes it to fall. Still another colleague claims they are both obviously wrong. Who is correct?

EQUIPMENT
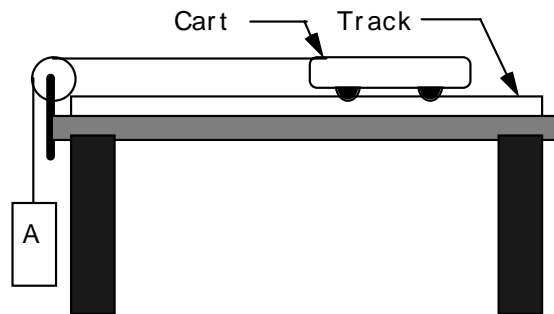
For this problem you will have an aluminum track, a PASCO cart, a stopwatch, a meter stick, a balance, weights, a pulley, a pulley clamp, one piece of string, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the velocity you need and another equation that expresses the force of the string on the cart. Make sure that you state any approximations or assumptions that you are making.

Sketch a graph of what you expect to see for the cart's velocity as a function of time, and position as a function of time, from the time of release until just before the hanging object hits the ground. What assumptions are you making to solve this problem?

<div style="text-align:center; border:1px solid black; display:inline-block; padding:10px;">

WARM-UP QUESTIONS

</div>

Read Serway & Jewett: sections 2.1-2.3, 4.4-4.6, 6.1, 6.5, and 6.6.

1. There are two important time intervals for this problem. The first is from the time the cart is released until the hanging object hits the floor. The second is from the time the hanging object hits the floor until the cart hits the end of the track. Make a drawing of the problem situation for each time interval. Draw and label vectors that describe the motion of the cart and hanging object during each interval. Label quantities in your picture you know or can measure.

2. Draw vectors to represent the forces acting on the cart <u>before</u> the hanging mass hits the floor. Draw force vectors for the hanging object while it is in motion. If forces are larger or smaller, be sure to indicate this with the length of the vector arrow you draw. Are the forces on the hanging object equal, or not? How do you know? Before the hanging object hits the ground, describe the motion of the cart (speeding up, slowing down, or staying constant).

3. If two quantities have the same magnitude, use the same symbol *and* write down your justification for doing so. Define a convenient coordinate system.

4. Draw vectors to represent the forces acting on the cart <u>after</u> the hanging mass hits the floor. Draw force vectors for the hanging object while it is touching the floor. If forces are larger or smaller, be sure to indicate this with the length of the vector arrow you draw. After the hanging object hits the ground, describe the motion of the cart (speeding up, slowing down, or staying constant). In each time interval, what quantities are constant and what quantities are changing?

5. To use conservation of energy, you must first define your system. For the time interval from when the hanging object is released until it hits the ground, define the system that you want to use. Write down conservation of energy for that system. Check that any energy transferred to or from your system is caused by forces from objects that are not in your system.

6. If your conservation of energy equation has the final velocity of the cart as a function of quantities that you know or can measure, you can go to the next part of the problem. If there is an unknown in your equation, define a different system where that unknown will also occur and write the conservation of energy for that system. Then use this to eliminate the unknown.

7. If you used systems in which the force of the string on the cart occurs in the conservation of energy equation, you can solve those equations for that force as a function of the mass of the hanging object and the mass of the cart. If the conservation of energy equation for your system did not include the force of the string on the cart, select another system in which it does occur. Now, solve your equations for the force of the string on the cart as a function of the mass of the hanging object and the mass of the cart. In either case compare this force to the weight of the hanging object. Are they equal? Why or why not?

8. Use the simulation "Lab4Sim" to explore the effects of a very wide range of masses for the hanging object and the cart. (See *Appendix F* for a brief explanation of how to use the simulations.) From the simulation try to address those questions. When the hanging object is *much more massive* than the cart, does the system have the final velocity you would expect? When the

hanging object is *much less massive* than the cart, does the system have the final velocity you would expect? Explain your reasoning.

EXPLORATION

Adjust the length of the string such that object A hits the floor well before the cart runs out of track. You will be analyzing a video of the cart both *before* and *after* object A has hit the floor. Is it possible to analyze both intervals at the same time, or do you need to analyze the video twice? Adjust the string length to give you a video that is long enough to allow you to analyze enough frames of motion.

Choose a mass for the cart and find a range of masses for object A that allows the cart to achieve a reliably measurable velocity before object A hits the floor. Make sure you include masses of object A that range from at least 1/2 that of the cart to masses that are a small fraction of the cart. Practice catching the cart <u>before</u> it hits the end stop on the track.

Make sure that the assumptions for your prediction apply to the situation in which you are making the measurement. For example, if you are neglecting friction, make sure that the cart's wheels turn freely. Also check that the pulley wheel turns freely.

Write down your measurement plan.

MEASUREMENT

Carry out your measurement plan.

Complete the entire analysis of one case before making videos and measurements of the next case. *A different person should operate the computer for each case.*

Make sure you measure and record the mass of the cart and object A. Record the height through which object A falls and the time this takes to occur.

Take a video that will allow you to analyze the data during both time intervals. Make measurements for at least two different heights of release.

ANALYSIS

Determine the velocities of the cart just before the hanging object hits the floor and just before the cart hits the end-stop. Examine the dependence of these velocities on the masses and the height of release.

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

CONCLUSION

How does the velocity of the cart depend on the masses and the distance traveled just before the hanging object strikes the floor? What is the relationship between the velocity of the cart just before

the hanging object hits the floor and the velocity just before the cart hits the end-stop? Did your measurements agree with your initial prediction? If not, why?

Which colleague was correct? Is the force of the string on the cart equal to the weight of the hanging object? Greater than that weight? Less than that weight? Explain your reasoning.

What is the total force on the hanging object? Is the force of the string on the hanging object greater than, less than, or equal to the gravitational pull of the earth on the hanging object? Explain.

Is the final velocity of the cart equal to the distance it goes divided by the time it takes to go that distance? Greater than that velocity? Less than that velocity? Explain your reasoning.

To launch a 3.5 kg model of a gliding dinosaur at a speed of 5.0 m/s, what should be the mass of the hanging object, assuming that it falls a distance of 1.5 m?

SIMULATION
If your data did not match your expectations, you should use the simulation to explore what could have happened.

If that is the case set the simulation to approximate the conditions of your experiment. Do you get the behavior, and the graphs of position and velocity, that you expect?

If you believe friction may have affected your results, explore its effects with the simulation. Does it affect the behavior, and the graphs of position and velocity, in the ways you expect?

If you believe that your prediction was incorrect because it did not take into account the effects of the mass of the string or the mass of the pulley, explore their effects with the simulation. Do they affect the behavior, and the graphs of position and velocity, in the ways you expect? Explain.

If you believe uncertainty in position measurements may have affected your results, use the simulation to compare the results with and without error. Can you more easily see the effect in the position vs. time graph or in the velocity vs. time graph? Did you see the effects of measurement uncertainty in your VideoTOOL measurements?

PROBLEM #6:
COLLISIONS

You are on a research team investigating the interactions of molecules that drive biological processes. Within a biological system, these molecules move at random until one collides with another. At that point they might stick together as when an active site of an enzyme attaches to a substrate. It is also possible that they will bounce apart. In both cases it is interesting to determine what happens to the kinetic energy of the molecules since this affects their mobility. Your assignment is to investigate the velocity of the resulting molecules after a collision. You decide to use conservation of energy to determine the speeds of the two molecules in the two cases of when they stick together or when they bounce apart. You know that molecules have structure so that some of the initial kinetic energy of the molecules can be transferred into internal energy of the molecule, molecular excitation. To simplify the possible situations, you take two simple cases. In both cases the molecules will have equal mass and one will initially be stationary and the other will be moving. In the first case the molecules will stick together and in the second case they will bounce apart. First you calculate the speed of each molecule after the collision ignoring any internal energy change. In each case what fraction of the initial energy do you think will be converted into internal energy? Then you write down the conservation of energy equation allowing for internal energy change and use you guess to calculate the final speed of each molecule. To test your results, you decide build a laboratory model using low friction carts and measure the amount of internal energy change when the carts stick together and when the bounce apart.

EQUIPMENT

You will have a meter stick, a stopwatch, two PASCO carts with Velcro and magnetic bumpers, an aluminum track, cart masses, wooden blocks, a camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).
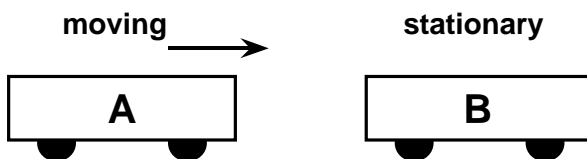
PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem for each case. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett: sections 6.1, 6.6, and 6.7.

1. Make two drawings. One that shows the situation before the collision and one after the collision for the case of a moving cart bouncing off of a stationary cart of the same mass.

Label the velocity vectors and masses for every object in both drawings. Define the most convenient system to use for conservation of energy.

2. Write down the energy conservation equation for this situation and identify all of the terms in the equation. Identify any energy transferred to or from your system by interactions with objects that are not in your system. Include a change in the system's internal energy that is some unknown fraction of the initial energy. Calculate this fraction as a function of quantities you know or can measure.

3. Repeat 1 and 2 for the situation where the carts stick together.

EXPLORATION

Practice setting the cart into motion so that the Velcro ends of the carts stick together after the collision. Also, after the collision carefully observe the carts to determine whether or not either cart leaves the grooves in the track. Adjust your procedure to minimize this effect so that your results are reliable. Be sure the carts still move freely over the track.

Try giving the moving cart various initial velocities over the range that will give reliable results. Note how fast the carts are moving after the collision. Does this agree qualitatively with your prediction? Keep in mind also that you want to choose an initial velocity that gives you a good video.

For collisions in which you want the objects to bounce off elastically instead of sticking together, experiment use the magnetic bumpers and repeat the procedures above.

Write down your measurement plan.

MEASUREMENT

Make all measurements necessary to check your predictions.

Analyze your data as you go along (before making the next video), so you can determine how many different videos you need to make, and what the carts' masses should be for each video. Collect enough data to convince yourself and others of your conclusion the fraction of the initial energy of the system that goes into internal energy. Also make sure that your data covers a range of initial velocities from very small to the largest possible without causing the carts to visibly vibrate on the track or move the track.

ANALYSIS

Determine the velocities of the carts (with uncertainty) before and after each collision from your video. Calculate the change in internal energy for each case. Compare with your prediction.

CONCLUSION

How do your measured and predicted values of internal energy change compare? What are the limitations on the accuracy of your measurements and analysis? In which case is there the most change in the system's internal energy. What is the change in internal energy? Could you ignore this change for either case as an approximation?

Surfaces	static	kinetic
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Steel on lead	0.9	0.9
Copper on cast iron	1.1	0.3
Copper on glass	0.7	0.5
Wood on wood	0.25 - 0.5	0.2
Glass on glass	0.94	0.4
Metal on metal (lubricated)	0.15	0.07
Teflon on Teflon	0.04	0.04
Rubber on concrete	1.0	0.8
Ice on ice	0.1	0.03
Wood on Aluminum		0.25-0.3

* All values are approximate.

☑ CHECK YOUR UNDERSTANDING

1. A cart and Block 1 are connected by a massless string that passes over a frictionless pulley, as shown in the diagram below.
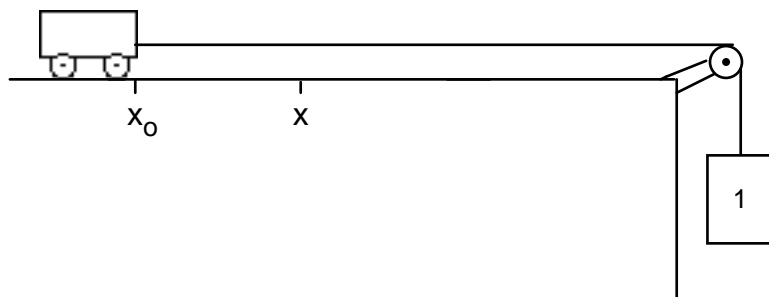
When Block 1 is released, the string pulls the cart toward the right along a horizontal table. For each question below, explain the reason for your choice.

a. The *speed* of the cart is:

   (a) constant.
   (b) continuously increasing.
   (c) continuously decreasing.
   (d) increasing for a while, and constant thereafter.
   (e) constant for a while, and decreasing thereafter.

b. The *force* of the string on Block 1 is

   (a) zero.
   (b) greater than zero but less than the weight of Block 1.
   (c) equal to the weight of Block 1.
   (d) greater than the weight of Block 1.
   (e) It is impossible to tell without knowing the mass of Block 1.

c. *When the cart traveling on the table reaches position x, the string breaks. The cart then*

   (a) moves on at a constant speed.
   (b) speeds up.
   (c) slows down.
   (d) speeds up, then slows down.
   (e) stops at x.

d. Block 1 is now replaced by a larger block (Block 2) that exerts *twice the pull* as was exerted previously. The cart is again reset at starting position x_O and released. The string again breaks at position x. Now, what is the *speed* of the cart at position x *compared to* its speed at that point when pulled by the smaller Block 1?

   (a) Half the speed it reached before.
   (b) Smaller than the speed it reached before, but not half of it.
   (c) Equal to the speed it reached before.
   (d) Double the speed it reached before.
   (e) Greater than the speed it reached before, but not twice as great.

TA Name:

PHYSICS 1201 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 questions 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.