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INTRODUCTION

As a TA in the laboratory, you must walk a very fine line. On one hand, you want to make sure that students complete their tasks and benefit from their experience. On the other hand, you cannot provide too much assistance or the students will refuse to work on their own and will be afraid to try out their own ideas. This instructor guide is meant to help you become a better coach to your students. This guide is not a substitute for the preparation you will need to do before teaching. Be sure you read the student lab manual completely. They will have questions. Also, do not let students see this instructor guide – should students have access to it, their discovery experience would become irrelevant.

THE GOALS OF LAB

The goal of the introductory physics labs at the University of Minnesota is to provide students with practice and coaching in using a logical, organized problem solving process to solve problems. The goal of the labs is the same as the goal of the discussion section — to help students slowly abandon their novice problem-solving strategies (e.g., plug-and-chug or pattern matching) and adopt a more logical, organized problem-solving procedure that includes qualitative analysis of the problem.

Since one reason that students cannot solve physics problems is that they have misconceptions about physics, a second goal is to confront some of those misconceptions in the laboratory. The labs include problems that try to illuminate known misconceptions and help students connect their lab experience to reality — all problems begin with a context statement. Now more than ever, the labs give the students a chance to learn physics in the real world. Because your students are so unfamiliar with this material, they may find the labs more frustrating than usual. This lack of familiarity coupled with misconceptions will often lead the students to conclude that the equipment "does not work," since it does not behave the way they think it should. If you are prepared, this is the ideal teaching opportunity. Your students will need you more than ever, and it is crucial that you are familiar with the equipment.

The U of M problem-solving labs do not contain step-by-step instructions; students are generally told what to measure, but they must decide in groups how to make the measurements (guided qualitative exploration). The students must also decide in their groups the details of the analysis. At the conclusion of the lab session, students must determine if their own ideas (predictions) match their measurements.

The lab's approach to confirmation of the physics concepts taught in lecture is subtle, and you must approach it carefully. On the one hand, the labs' primary purpose is not this confirmation; on the other, there is some aspect of this in the confrontation of misconceptions. The bottom line is that although you should not direct your efforts primarily at confirmation of physics concepts, students should not leave lab believing they have shown that what they have been taught in lecture is wrong.

LAB SESSION STRUCTURE

OPENING MOVES

Typically, the first 15–20 minutes of lab are spent preparing students for group work and focusing the lab session on what students should learn. Your “opening moves” as a TA begin when you ask the members of each group to arrive at a consensus about one or two of the warm-up and prediction questions. You should decide which warm-up questions to have students discuss and put on the board from your examination of the answers your students turned in before lab. Make sure to give an explicit time limit for this group discussion; for most lab problems it should take no more than 5–10 minutes (however the discussion for more difficult problems may take longer.)

At the end of the group discussion time, have one representative from ach group put their group’s answers to the selected warm-up questions on the board. Ask each group to give their reasons for their answers, and then conduct a class discussion comparing and contrasting their answers and reasons. The discussion need not arrive at the correct answers to the questions. In fact, more learning occurs in a lab session when there are unresolved disagreements. Wait to resolve the disagreement in the closing discussion, after students have completed checking their solution.

After the opening discussion, briefly discuss the measurements students will make to check their solutions. It is often a good idea to ask students, “What are we trying to measure in this lab?” to get their mind focused on the target quantity or quantities. This is also a good time to point out the pieces of equipment they will be using, or give particular instructions about the equipment. This instructor’s guide also includes suggestions for what to discuss. For the students to get the most out of their lab experience,

DO NOT LECTURE DURING LAB! EVER! UNDER ANY CIRCUMSTANCES!

Reasons:

1. There is already a lecture component of the course; lab is a time for students to apply the theories from their text and lecture. Even though they are unsure of themselves and might think they would benefit from explanations of the material, more lecturing will not help - experience and coaching will. Do not reduce the time the students need for hands-on learning activities. If students have not yet attended a lecture on the material, you might need to give them helpful hints to get them started, but keep it short. The lab experiences will serve as a good introduction to the material when it comes up in lecture.
2. If you give the students the answers before they start, you are telling your students that you do not care about their ideas and that they should not care either. Answer their questions only after they have made their best attempt to answer it themselves and within their groups. Let them investigate their own ideas to find which are correct and which are misconceptions. When they are cognitively engaged, they learn.
3. Lecturing often places the listeners in a passive mode, but effective learning takes place in an active mode. Students are in an active mode when they are doing or thinking about a specific problem. Active modes are what the laboratory and discussion sections are designed to evoke.

It is your responsibility to inform the professor for the course if the lecture and lab topics are not synchronized, or about any other problems involving the lab and lecture sequence. If you notice this is the case, bring it up at your team meetings and respectfully request a slower pace until the lectures catch up, or discuss alternative methods to approaching the lab topics. **It is the professor's responsibility to ensure that students are familiar with the concepts** necessary for lab **before** they enter the lab room. **You should resist** if the professor asks you to introduce a new topic in lab by giving students a lecture! Another option is to hold a problem solving session during lab to allow the lecture to "catch up."

MIDDLE GAME

During the lab session, your role is one of observer, listener, and coach. You should circulate around the room, observing what groups are doing, listening to what students are saying, and observing what the groups are writing in their lab journals. Intervene when a group needs to be coached on an aspect of physics or the Exploration, Measurement, or Analysis procedure.

It is your job as a TA to guide the lab groups and help them focus their questions. Here's where you really earn your money, because it's up to you to decide when and how to help the student groups. It is important that they attempt to work through the problem themselves. However, if they struggle too much they will gain nothing from the lab except frustration and despair.

With 10-20 minutes left of class, have a representative from each group put their group's corrected answers to the warm-up questions on the board (if possible, below their original answers.)

END GAME

A good end game helps students consolidate their ideas and explicitly summarizes the learning focus for the lab session. Give students a few minutes to examine what other groups wrote on the board, and then lead a whole-class discussion of the results (how do their measurements and predictions compare?) and the objectives for the lab session. Depending on time constraints, you may decide to discuss some of the answers to the warm-up and prediction questions.

When you were an undergraduate, your laboratory instructor probably did not stop you to have a class discussion. Doing this is one of the hardest things you will have to do as a TA. You may be tempted to either let students keep working so that they can get as much done as possible, or let them go home early so they will like you better. However, students do not learn from their laboratory experiences unless they are actively engaged in figuring out what they have learned.

TEACHING TIPS

1. Carefully tell the students what you expect of them in the laboratory and why these rules are necessary. Be very strict in enforcing these rules during the first half of the semester. It is easier to establish good habits in your students early in the semester than to try to establish them later. If you are strict and fair, your students will respect you for it. If you do not consistently enforce your rules, some students will never believe anything you say. If you have any questions about this concept, please talk about it to your mentor TAs.
2. Always tell students explicitly that they should hand in answers to both the Predictions and Warm-up questions for the problem(s) that you assign before they come to lab. The deadline for handing them in will be decided in your teaching team — it is usually 1or 2 days before the lab session. Make sure the students understand that the warm-up questions are there to help guide them through the analysis, as well as to help them solve the problem.
3. It is well known that students do not like to read instructions. They will come to you and ask questions that are answered in the lab manual. If this happens, first ask the student a question to determine if they have read the manual. If not, refer them back to the manual. If they have, give them a straightforward answer.

Tell the students what resources are available to them and encourage going to the tutor room 137 if they have any questions. The student lab manual has plenty of information in the appendices. For example, there are sample lab reports (**Do not assign these problems** for reports!).

SAFETY

Your students' safety is your first responsibility. A first aid kit is available in equipment closet #7 on the second floor for minor cuts and scrapes. Make sure you are the only person to access the kit unless there is an emergency and an urgent need to do otherwise.

It is important to **verbally warn students about potential dangers.** The lab manual and this guide provide warnings, which are marked with a symbol of a hand with one finger raised in warning, as seen to the left**.**

EQUIPMENT

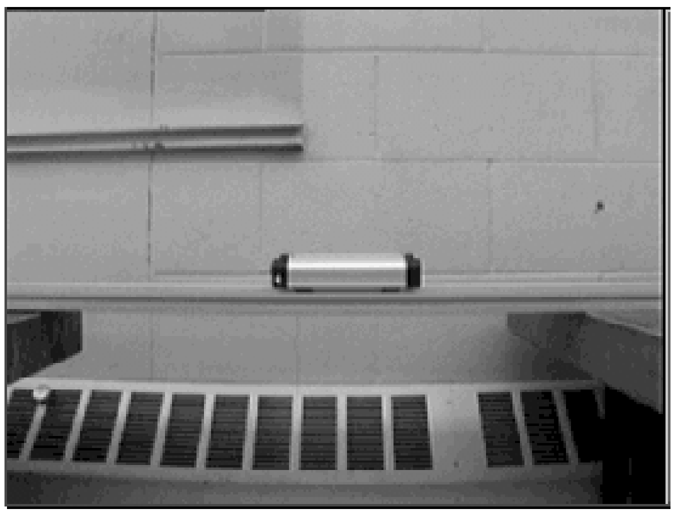
- If there is any bad, broken, or erratic equipment, e-mail directly to the lab coordinator at labhelp@physics.umn.edu. Be sure to include a complete description of the problem, and the room number. If the problem isn't corrected during your lab, **make a note on the** blackboard to inform the next TA of the problem, and that a problem report form has already been submitted.
- Be sure that your students treat the equipment with respect. Keep the following in mind:
  - After the students have finished with the computers and cameras, have them turn off the power to the computer.
  - Never turn off the power to a computer without shutting it down first.
- If there is no video image in the VideoRECORDER window, check the following:
  - The camera is plugged in to the computer.
  - The camera light is indicating power.
- Some suggestions about the camera and video analysis program:
  - Take a few moments to learn how to focus the camera.
  - The object the students use to calibrate their movies MUST be in the plane of motion of what they are measuring. A good example of this is the circular motion problems in Lab 2. See the Instructor's Guide for Lab 2, Problem #'s 5-7 for an example of how the calibration makes a big difference.
  - Keep the camera level with the motion being recorded.

Make sure to tell students to write in their lab journals their predictions and data fits as they go (including both the equation and the coefficients). The computer will not show these values once they move to a different stage in the analysis. This is done on purpose to force the students to keep an organized lab journal.

SOME HINTS TO MAKE SURE YOUR STUDENTS HAVE USEFUL MOVIES

You will have to keep quite a close eye on your students' movie making within the first few weeks of class to help them get into good habits. You should use Lab 1, Problem #1 to help them explore some of the possible pitfalls. If their movies are poor, their conclusions will be incorrect, perhaps perpetuating the misconceptions they brought to class.

A good movie



Notice that in this movie frame:

- The camera is level with the cart's motion.
- The cart's motion is centered in the screen.
- The cart's motion will fill the entire screen.
- The camera is the "perfect" distance away from the cart. If we were closer, we wouldn't have as many data points. If we put the camera further away, we'd find that the picture would be fuzzier.
- The adjustments on the camera are just about right. The picture is not too light, nor is it too dark and the cart is in focus.
- In this case we would use the cart to calibrate the movie. It is in focus, and more importantly, it is in the plane of motion.

A bad movie

Notice that in this movie frame:

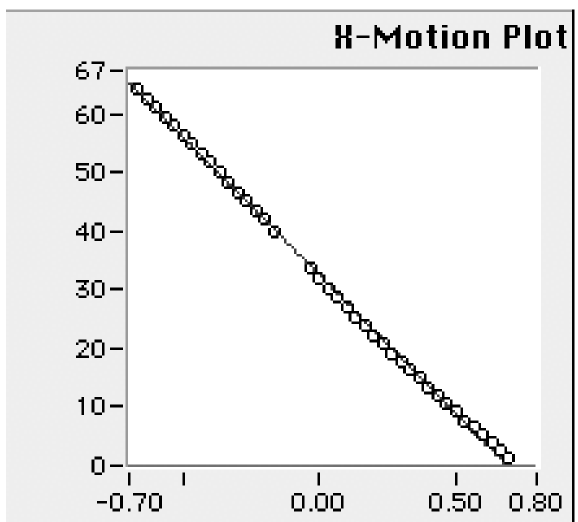
- The camera is not level with the cart's motion. The video is shot from above, which causes the cart's image to be distorted. Notice that the right side of the cart is visibly closer to the camera than the left side. Thus our 2-D picture has a 3-D component for which we cannot account – this will cause the analysis of the movie to be incorrect.
- The cart's motion takes place only in the top portion of the screen. (When your students do Lab 1, Problem #1 you should have them investigate not only the distortion at the side of the screen, but also at the top and bottom.) You can even see that the track looks like it is curved.
- The camera is a bit too far away from the cart. It is thus more difficult to focus on the cart.
- The adjustments on the camera are not correct. The picture is obviously too light since we can't even make out the top edge of the cart. The focus is as good as we could get it at this distance (which is not very good).
- The students WILL make movies like this and then wonder why their conclusions are coming out incorrectly. The first thing that you should check when the students come to you with bad conclusions is their movie. The next thing to do is ask them what they used to calibrate the movie. If they used an object that is not within the plane of the motion of interest, their results will most likely be wrong (in most cases, VERY wrong).

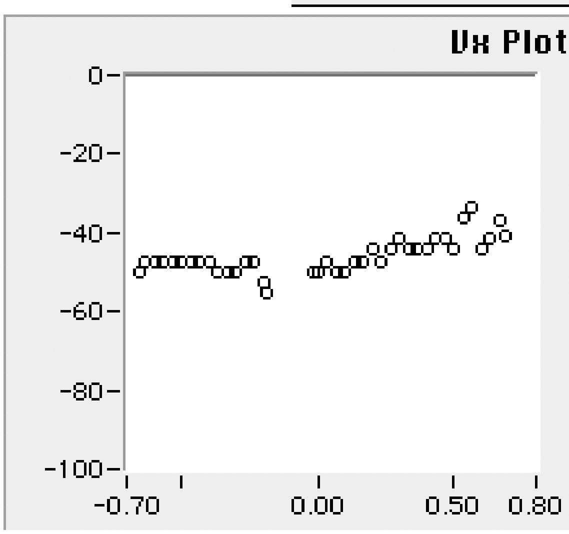
Analysis of our movies

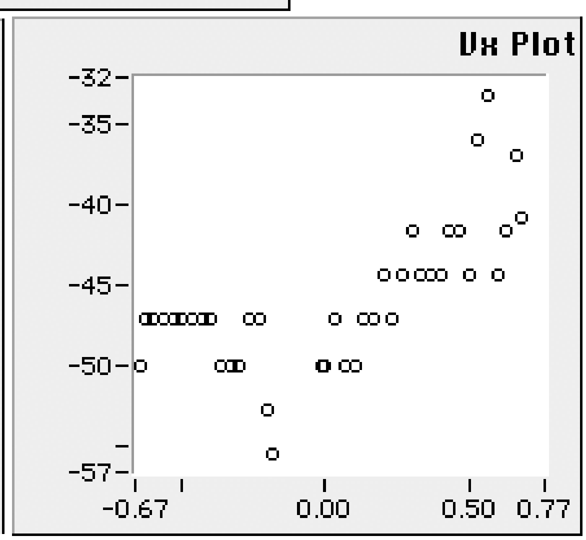
Here we analyze the movies (two frames of which are shown on the previous pages). The motion is that of a cart moving with constant velocity along the track. Although the velocities are different, we can still use the movies to compare what are considered good results with those that are bad.

The good movie

Below are the position and velocity graphs for the good movie. Notice that even though we went to great lengths to make this movie well, the x versus t graph of constant velocity motion is not quite a straight line and the computer skipped some frames (the missing data points in the middle of the graph are indicative of frame-skipping). Retaking the movie would probably eliminate the skipped frames. The plot curves slightly at the edges of the video screen – which is exactly what your students should be looking for when they go through Lab 1, Problem #1.





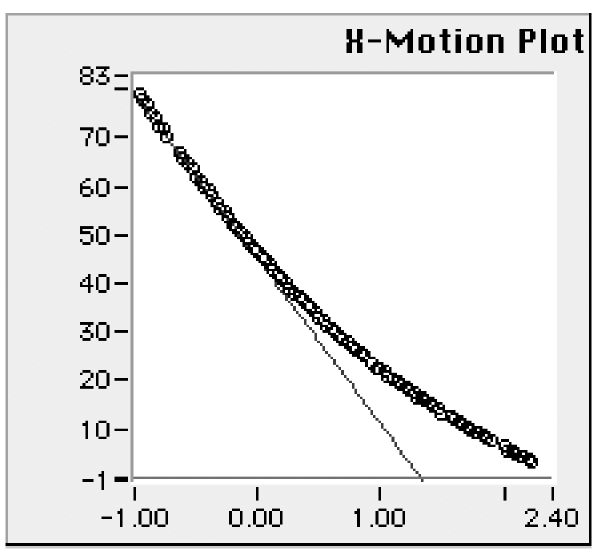


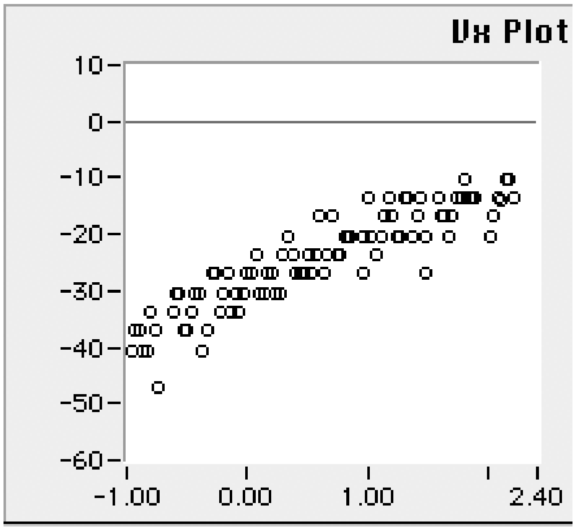
We include two velocity-versus-time graphs for the good movie. In the plot on the left we put in the axis limits ourselves. The plot on the right is "autoscaled." (Both plots are identical except for the y-axis scaling.) We include both graphs to show how "autoscale" may mislead the students into thinking their data is not very good. The students should really only use this feature to help them find their data before analysis. Even the plot on the left shows that our efforts to make a good movie were not perfect. With practice, students should be able to reduce the scatter. In this case we would have the students use the slope of their x versus t graph for their experimental velocity.

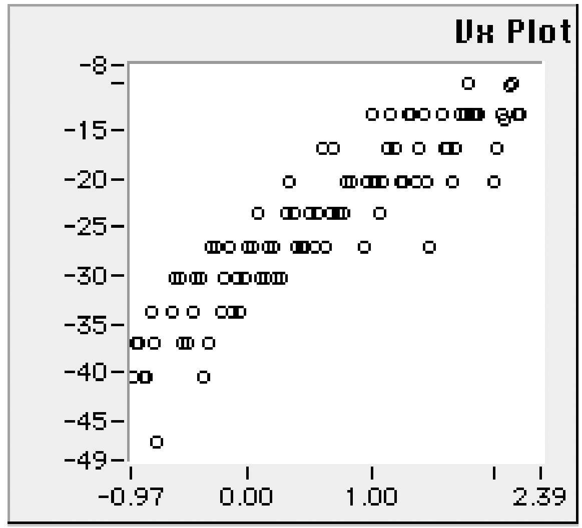
You may have noticed that some of the data points were taken at "negative" time (the horizontal axis is the time axis). This is due to the fact that we forwarded the movie to the frame in which the cart was at the center of the screen to do our calibration. We then reversed the movie so we could start taking data points when the car just appears on the screen. The calibration point is the point at which the computer attaches t = 0. Make sure your students understand why their time (or position in some cases, e.g., analysis of a falling ball) is negative.

The bad movie

Below is the analysis of the bad movie. The x versus t graph is NOT the expected straight line. For most problems, this type of poor analysis would cause the students to have conclusions that are not within 10% of the correct result. The cart in this movie was going slower than in the good movie (and the camera was further away), so we have many more data points. In reality there are too many data points. It is tedious to go through every frame of the movie, so you may want to suggest that the students use the controls on the bottom of the movie player to "fast-forward" through some of the data (e.g., perhaps they could skip every other data point). The computer will take the time difference into account. Of course a "good" movie should be designed to avoid taking too many data points, but sometimes it is unavoidable.







Again we include an "autoscaled" graph (on the right) and one we scaled by hand. There is obviously a non-zero slope in these velocity-versus-time graphs, along with the scatter discussed previously. After seeing this plot, it is more apparent that the velocity-versus-time graph for the good movie is that of constant velocity. It may be instructive to have your students go to these extremes when working through Lab 1, Problem #1.

USING THIS INSTRUCTOR'S GUIDE

This instructor's guide is designed to help you help your students. Despite that, don't rely on this guide too much. **It is not a substitute for preparation**; it is only a guide for preparation. Also, **don't let students have access to it**. It's basically like having a solution manual for textbook problems. It can short circuit the learning process.

We are continually working to improve the instructor's guide. To add any suggestions, you should write down notes and suggestions on the TA Lab Evaluation found at the end of the Instructor's Guide. Return these forms labhelp@physics.umn.edu or one of the mentor TAs.

Information from previous laboratory instructors was used to construct this guide as well as modify this year's student lab manuals. Your input is greatly appreciated. Include anything that you feel will be useful. Your notes may include additional comments to be included in the Instructor's Guide, difficulties you or your students had with the problems or the apparatus, and suggestions for changes in the labs.

At the start of each chapter in this guide is a flow chart that shows the connections between the different problems in that lab. This chart is designed to help you plan your lessons. The elements of the flow charts have the following definitions:

- Bold ovals are the problems that contain knowledge and techniques that are prerequisites to other problems. It is strongly suggested students be required to do these problems.
- The arrows on the connecting lines are directional symbols.
- Dashed lines are optional paths.
- The X across a connecting line implies that if a group has completed one of the problems, that group should skip the other problem.
- Any one group can do any number of problems on the same level.

As the instructor who knows the students, you are the only one who can determine the right number of problems for a given group to solve to keep them intellectually engaged in the primary purpose of the laboratory. If you assign too many problems to a group, the students may simply rush through data taking without spending enough time exploring their own ideas or the real behavior of the apparatus. If you assign too few problems, they may not get the repetition they need to consolidate their developing sense of physics or come to grips with a topic that will help them identify a misconception. Because your groups will be different, it is not necessary or even desirable that all groups complete the same number of problems in a laboratory. From past experience, an average of two problems per week is the usual range that a group can complete. The minimum for a two-week laboratory is usually three problems and the maximum is five.

The range of available problems allows you to assign tasks to groups that reflect the needs of the students in that individual group. Some problems are basically repetitions of a previous problem for those groups who you judge do not quite understand the central idea of the lab. Others are challenging extensions to enable groups that solidly understand the basic concepts to increase their knowledge. The problems you assign should also reflect the emphasis of the class, which is decided upon in your team meetings.

LABORATORY 1: DESCRIPTION OF MOTION IN ONE DIMENSION

Laboratory 1 has eight problems (with one divided into two parts). Remember, the purpose of the laboratory is to allow students to examine their own ideas about the basic concepts of physics and how to apply those concepts to the REAL world using a logical and organized problem solving procedure. As the instructor who knows the students, you are the only one who can determine the right number of problems for a given group to solve to keep them intellectually engaged in the primary purpose of the laboratory. If you assign too many problems to a group, the students may simply rush through data taking without spending enough time exploring their own ideas or the real behavior of the apparatus. If you assign too few problems, they may not get the repetition they need to consolidate their developing sense of physics or come to grips with a topic that will help them identify a misconception. Because your groups will be different, it is not necessary or even desirable that all groups complete the same number of problems in a laboratory. From past experience, an average of two problems per week is the usual range that a group can complete. The minimum for a two-week laboratory is usually three problems and the maximum is five.

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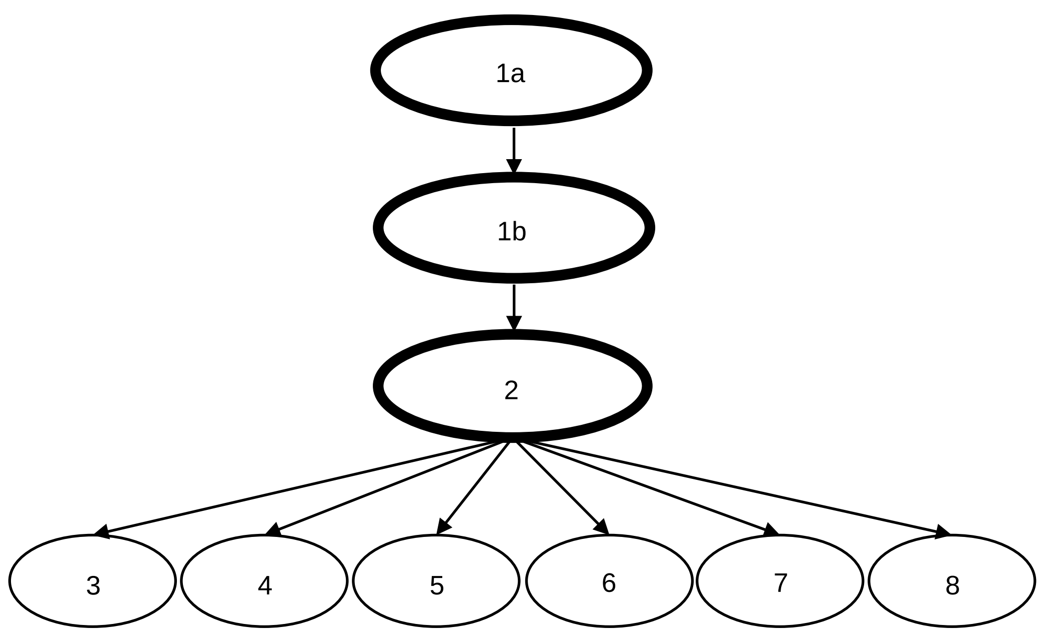


(For an explanation of the elements of the above flow chart, please refer to the bottom of page 1 of Introduction.)

GENERAL TEACHING TIPS

- Every group needs to do problems 1a, 1b, and 2 (measurement and uncertainty, constant velocity motion, and constant acceleration motion, respectively) to prepare for the others.
- Problems 3–5 have about the same difficulty and each deals with a different misconception about motion. Use the students' answers to the first set of predictions and your discussions with them both in laboratory and recitation to help you select problems for a particular group. If the first laboratory lasts for 3 weeks, most groups should do them all.
- **Do not** use the concept of force to explain phenomena in this lab. The students may not know anything about forces yet.

BY THE END OF THIS LAB, STUDENTS SHOULD BE ABLE TO

- Describe completely the motion of any object moving in one dimension using the concepts of position, velocity, and acceleration, and time.
- Distinguish between average quantities and instantaneous quantities when describing the motion of an object.
- Express mathematically and graphically the relationships of position, time, velocity, average velocity, acceleration, and average acceleration for different situations.
- Analyze graphically the motion of an object.
- Begin using technical communication, keeping a laboratory journal and writing a laboratory report.

BEFORE YOU SEE YOUR STUDENTS

- Check the cart wheels to see if they can rotate at least two seconds by a gentle push.
- See how fast/hard you can safely push the carts.
- See how slowly/softly you can push then and get reasonable results.
- Determine the best setup and use of the camera.
- Find the range of angles that gives the best results for motion up/down an incline.
- Try the cart with an elastic cord (Problem #6) to see the limits of stretching. Try to determine where students may run into trouble.

LAB 1, PROBLEM 1A: INTRODUCTION TO MEASUREMENT AND UNCERTAINTY

PURPOSE

- Give the students experience measuring things and calculating the uncertainties of those measurements
- Give the students a guided exercise so that they can develop their ability to work in groups by organizing tasks and discussing what they think
- Practice fitting equations

TEACHING TIPS

This is your first lab activity, and you need to set a good standard for the rest of the semester. You need to figure out what kind of teacher you will be, but here are some tips that anyone can incorporate no matter how long they've been teaching.

- For at least the first two weeks, dress more formally than you normally do. It helps the students see you as an authority and take you seriously
- Present the lab rules and protocol clearly. Even though you will give exceptions to certain circumstances as they come up, you need to state what will be expected of the students.
- Get them to ask questions. About anything. While you want to be taken seriously, you also want them to see you as someone that can help them when they are confused.
- Start using their names right away. Guess if you don't know. You are allowed to make mistakes in the first couple of weeks. They will appreciate that you are trying.
- Discussion, discussion, discussion! Get them accustomed to sharing ideas with each other before they ask you
- Keep them from rushing through things on the one hand and from going too slowly on the other. You have to monitor the groups' progress because they must get through the whole lab to have the video analysis experience. You might consider dropping either the length or the time measurements as necessary.
- Wander around and talk to the groups. Even if they don't have questions, stop them and have them explain what they are doing and why. This is the time to set up the protocol for the semester.

This problem incorporates the PracticeFIT program, which will familiarize students with matching equations to graphs of several "Mystery Functions" (see table below). Many students have trouble with this. This exercise should be useful to almost every student at the beginning of the semester, since they will find equations to match graphs nearly every time they use the computer. In particular, the program familiarizes students with

- manipulating axis bounds to "see" data points;

- the dependence of graph shape on function type;
- the dependence of graph shape on the constant parameters in different types of functions.

The program allows students to try several graphs in a short time. You may have students try particular "Mystery Functions" to work on specific difficulties.

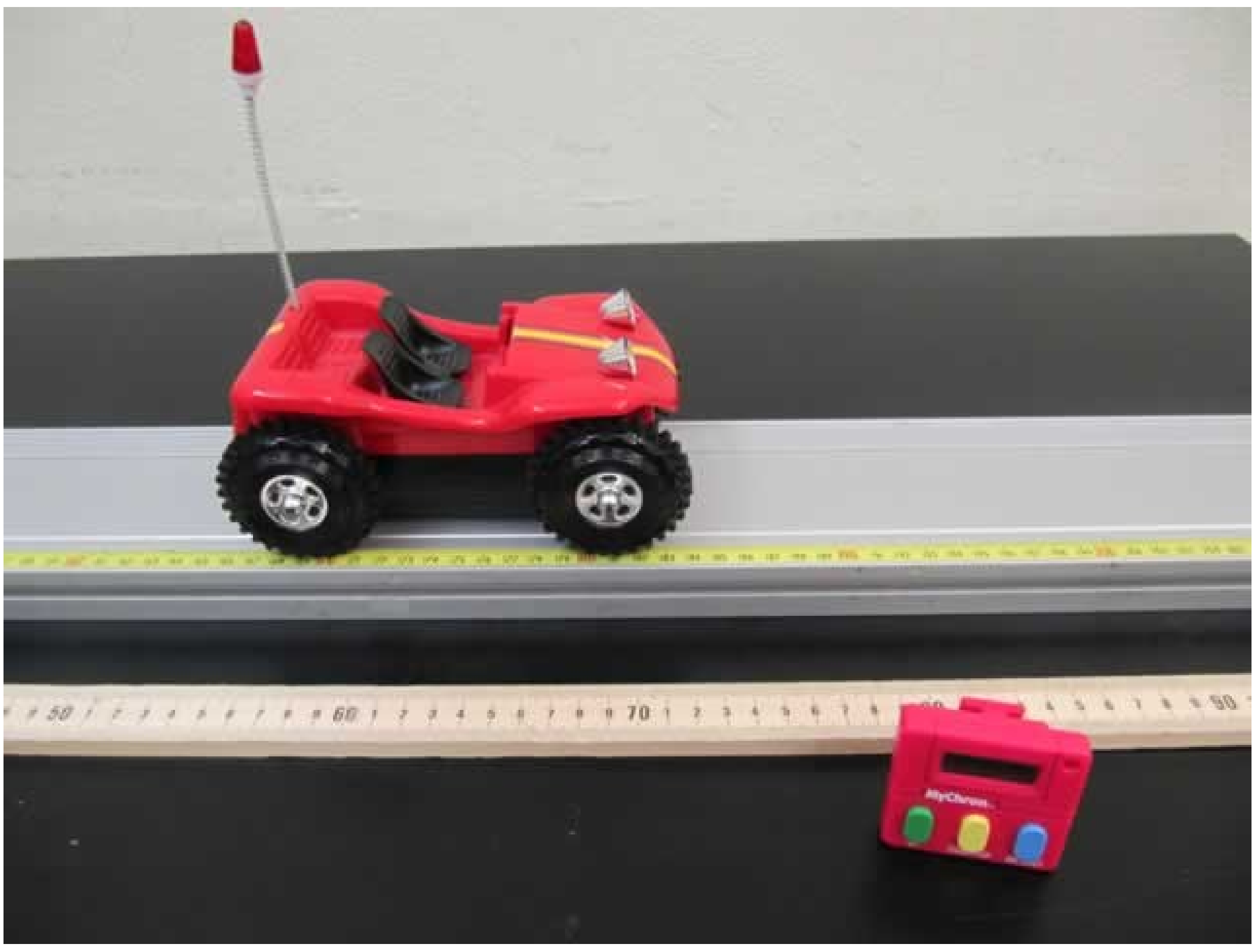
Targeted use of the PracticeFIT program could be useful to particular students later in the semester.

Mystery Function	**COMMENT / Details**
1	SIMPLEST / Linear; u(t) = A + Bt; A is random integer in [-5,5]; B is random half-integer in [-2.5,2.5]
2	ALWAYS FORCES STUDENTS TO ADJUST AXIS SCALES / Linear; A is decimal in [-24.0,-15.0] or [15.0,24.0]; B is decimal in [-5.0,5.0]
3	PARABOLA, SYMMETRICAL AROUND X=0
4	PARABOLA
5	SIN FUNCTION
6	SIN FUNCTION WITH PHASE SHIFT
7	EXPONENTIAL
8	RANDOM FUNCTION, UP TO 3 NON-ZERO PARAMETERS
9	RANDOM FUNCTION, UP TO 4 NON-ZERO PARAMETERS
10	RANDOM FUNCTION, UP TO 5 NON-ZERO PARAMETERS

LAB 1, PROBLEM 1B: CONSTANT-VELOCITY MOTION

PURPOSE

- To introduce students briefly to the need for experimental technique, by having them think critically about the video camera lens distortions and if the imperfections will affect their results.
- To familiarize students to the camera and video analysis software that will be used frequently throughout the semester, and to show its limitations, features, and reliability.
- To solidify the relationship between position, velocity, and acceleration for constant velocity.
- To get the students thinking about experimental uncertainty.



EQUIPMENT

TEACHING TIPS

- Every group must do this problem. Since it is the first lab, it will take longer than you think. Give them at least 40 minutes to work with the equipment.
- Be sure to go over the introduction to the labs with your students. **Do not assume they will read it.** It is included in the lab manual to allow the students to reference it throughout the semester.
- Students become overwhelmed by the computer and forget the purpose of this lab. You will need to remind them that they are looking for the effect of the lens distortion.
- When the students use the video analysis software to examine the motion near the left and right sides of the video image and find velocities in this region, they should see a dramatic effect. The apparent velocity near the edges of the video image in one case was measured to be about 25% less than the actual velocity seen in the middle of the image. This percentage will vary, depending on how much care the students put into making their movies.
- You should suggest to your students that they should investigate the upper and lower regions of the screen along with the left and right. This is their chance to understand the limitations of the camera. If they don't understand these limitations, they are certain to have difficulties later in the semester. You may want to have them make good and bad movies and compare them.
- Since the video analysis software calculates the velocity data from the position data using simple point-by-point differences, the velocity data always appears somewhat scattered. This scatter will be reduced if the students are careful in collecting their data. Part of the purpose of this lab is to get the students acquainted with experimental uncertainty and how to limit it.
- Most groups will only want to analyze one movie. You should therefore make it clear, early in the semester, that the measurements should be done more than once. Emphasize the importance of reproducibility.
- Make sure everyone in each group gets the chance to analyze a movie. There tends to be at least one computer hog per group, and some students will be left out unless you intervene.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Many students have difficulty connecting graphs with physical equations, or connecting graphs with genuine motion. Make sure that everyone knows how to graph the simplest possible motion before moving on to more difficult cases.

It may take **repeated explanations** until the students learn that average velocity is not the same as instantaneous velocity at all times.

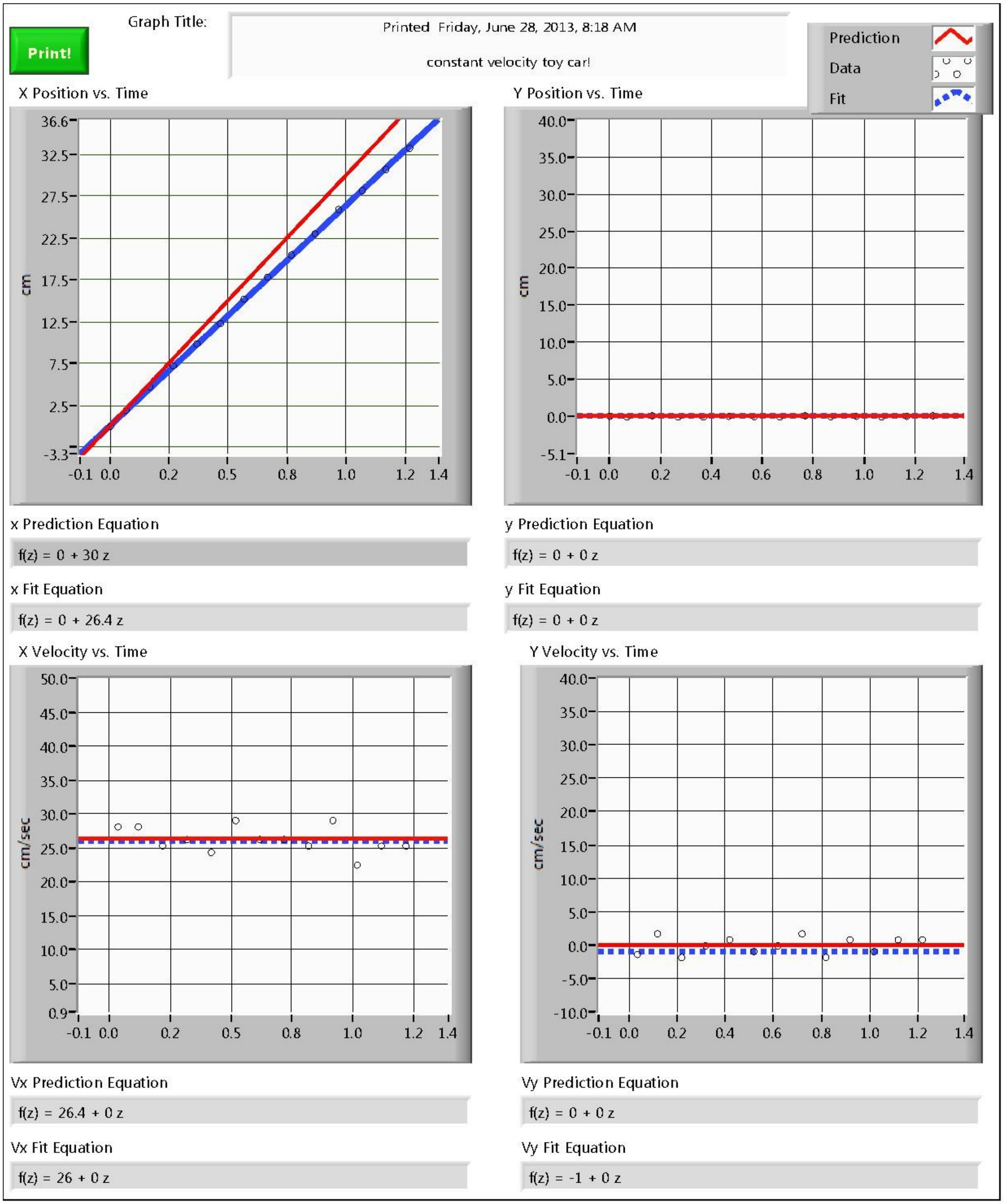
PREDICTION AND WARM-UP QUESTIONS

The prediction and warm-up questions are straightforward, and the prediction does not require any derived equation.

Note: In all cases the prediction and Warm-up questions are your responsibility. You must complete them on your own in preparation to teach. Only for the more complex labs will this guide provide you the answer to the prediction. Use this guide as a check to make sure your work is correct.

SAMPLE DATA

Velocity of toy car was about 26cm/s.



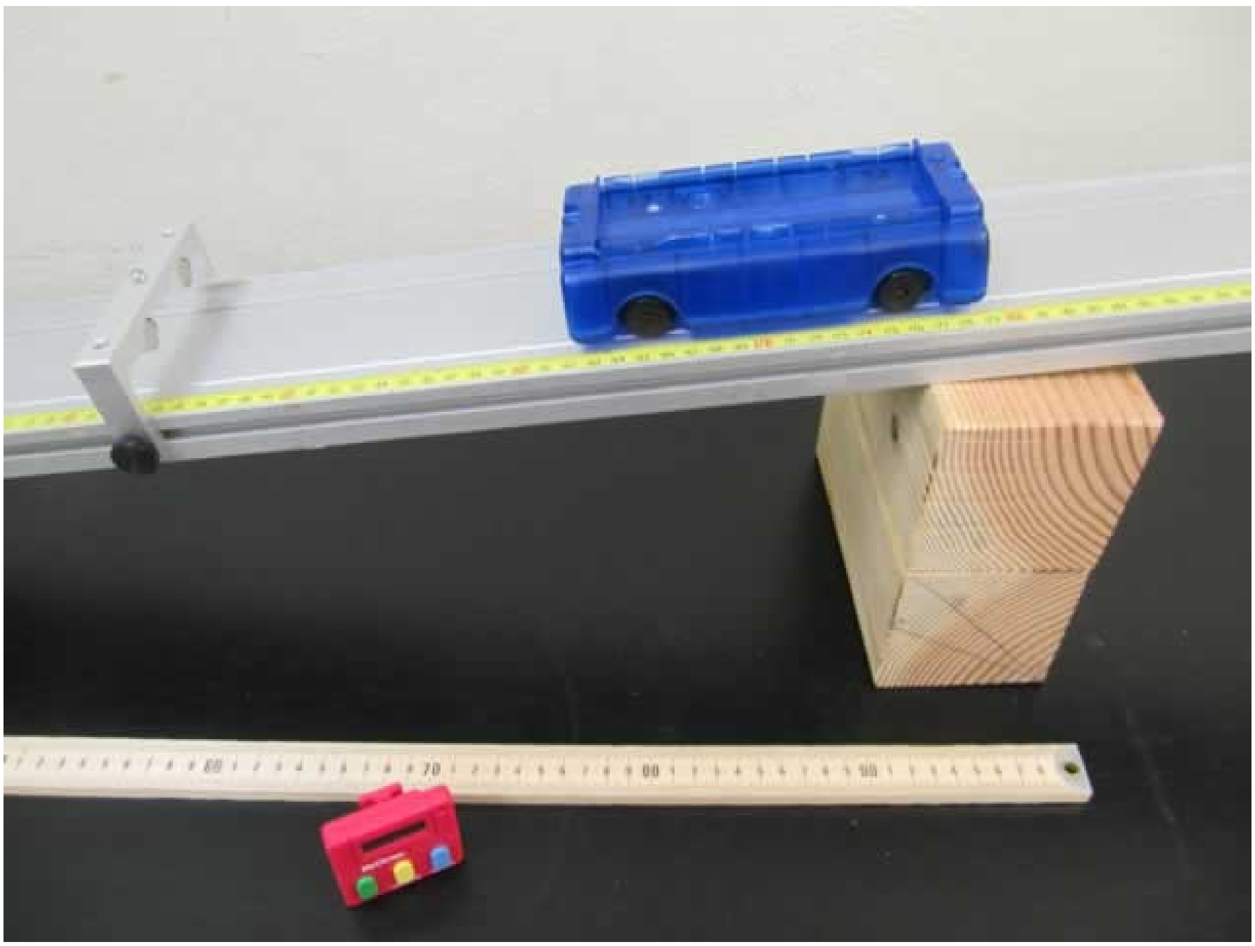
LAB 1, PROBLEM 2: MOTION DOWN AN INCLINE

PURPOSE

- To show that there is a constant, non-zero acceleration of the cart down an inclined track.
- To recognize that in this situation $v_{\text{avg.}} \neq v_{\text{inst.}}$ but $a_{\text{avg.}} = a_{\text{inst.}}$ because the acceleration is constant.

EQUIPMENT

Track, end stop, card, wooden blocks, meter stick, stopwatch



TEACHING TIPS

- Every group should do this problem. Matching data to a parabola is a difficult task. (Don't forget the "$\frac{1}{2}$" in $x(t) = x_o + v_o t + \frac{1}{2}at^2$.) To get an accurate acceleration, the students will need to match the velocity-time data. They will need the skills they develop here to do any of the problems that follow.

- A good topic for an entire class discussion (or even in groups) is to compare how this motion is different from constant velocity motion in each of the three representations (displacement in each time frame, graphical, and mathematical).
- (Optional) It may be instructive to have the students use the data table to create their own velocity vs. time graph, then compare their graph to the one the computer generated. This task should make it clear to them how the computer creates the graphs.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Acceleration and velocity are hotbeds of alternative conception. In this problem we are trying to get the students to distinguish between velocity and acceleration, between position and displacement, and between average and instantaneous quantities.

Students recognize that the acceleration down the track is caused by gravity. At this point, your students cannot determine that the acceleration is g sinθ. It is important that they have an idea of why the acceleration is a fraction of g. (Note: the reason that the acceleration is g sinθ is not because it is a component of g. Rather, one must analyze the forces, which your students will do later, to determine the acceleration.)

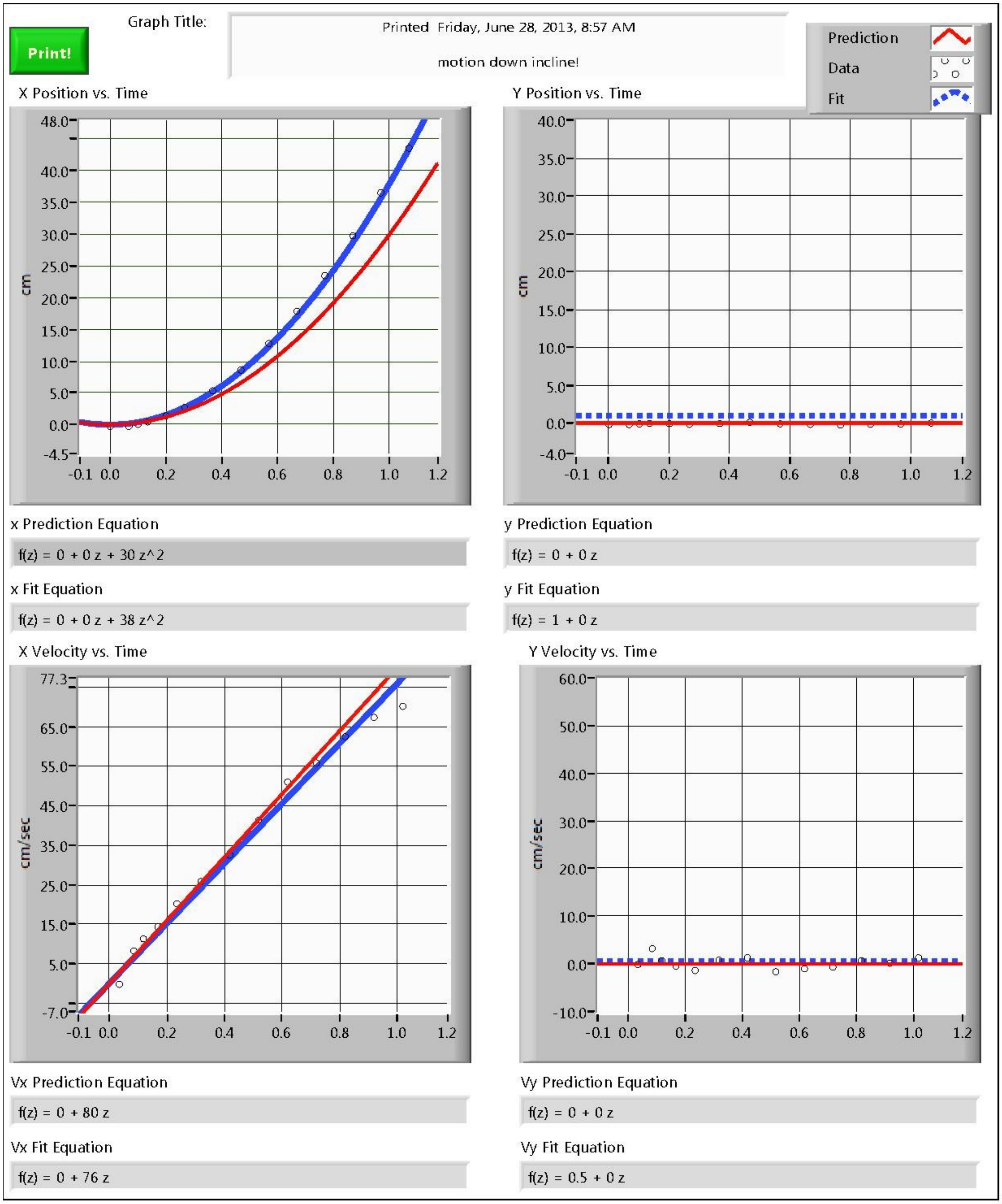
PREDICTION AND WARM-UP QUESTIONS

Graph of constant acceleration.

SAMPLE DATA

Inclined angle: $\mathrm{Sin}^{-1}(18.0\mathrm{cm}/220.0\mathrm{cm})$

Acceleration: $a = 76\mathrm{cm/s}^2$


Print!
Graph Title:
Printed Friday, June 28, 2013, 8:57 AM
motion down incline!
Prediction
Data
Fit
X Position vs. Time
Y Position vs. Time
cm
x Prediction Equation
f(z) = 0 + 0 z + 30 z^2
x Fit Equation
f(z) = 0 + 0 z + 38 z^2
y Prediction Equation
f(z) = 0 + 0 z
y Fit Equation
f(z) = 1 + 0 z
X Velocity vs. Time
Y Velocity vs. Time
cm/sec
Vx Prediction Equation
f(z) = 0 + 80 z
Vx Fit Equation
f(z) = 0 + 76 z
Vy Prediction Equation
f(z) = 0 + 0 z
Vy Fit Equation
f(z) = 0.5 + 0 z

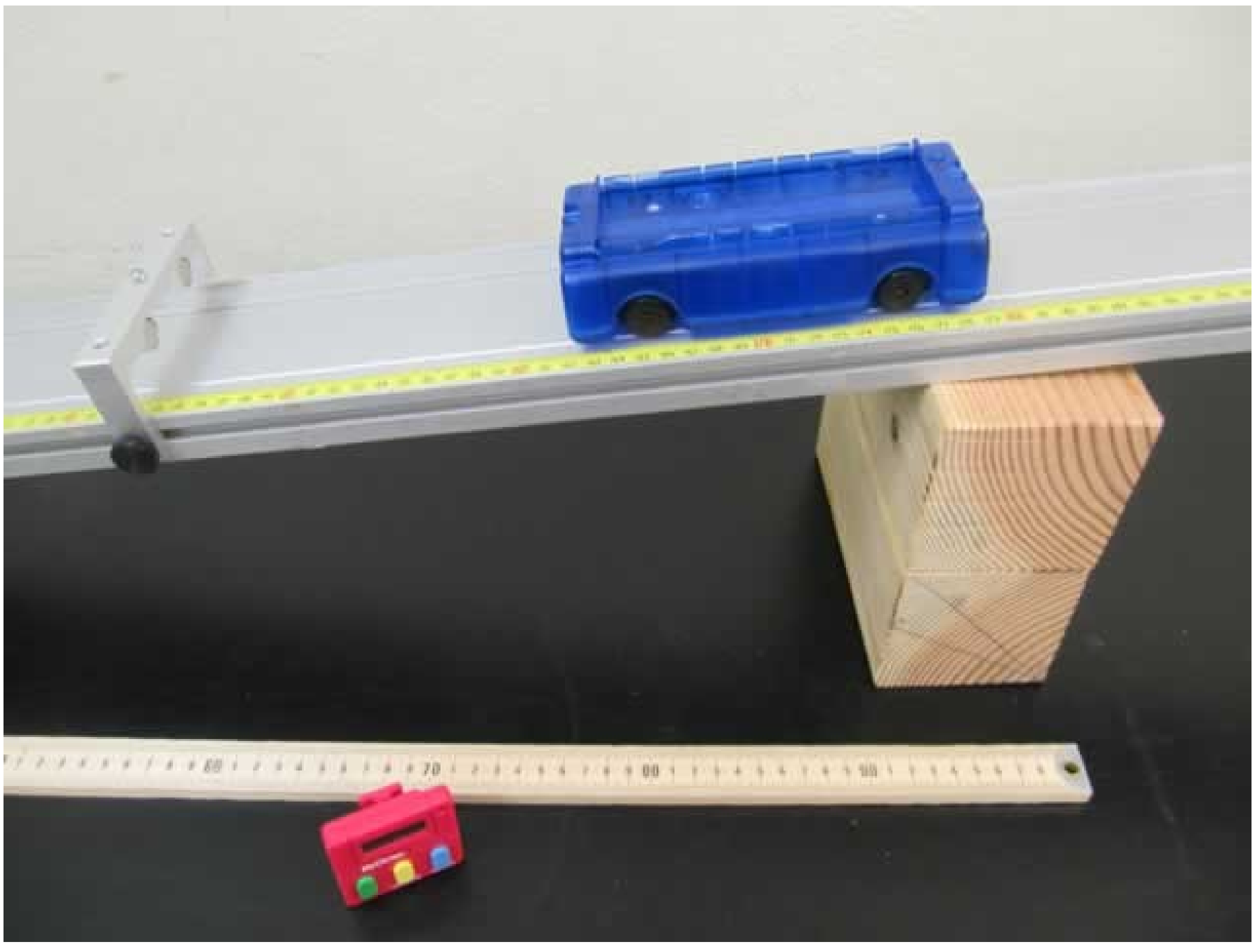
Lab 1, Problem 3: Motion Up and Down an Incline

Purpose

To show students that the acceleration is the same for motion both up and down an incline.

Equipment

Track, end stop, card, wooden blocks, meter stick, stopwatch



Teaching Tips

Have the students compare the results of the motion of the cart up and down the incline. Watch for students who think the acceleration changes direction for the two cases. The graphical analysis is very useful here if the students understand the meaning of the slope of the velocity vs. time graph. If a group is having trouble, it is useful to ask the direction of the change of velocity as the cart goes up the ramp, comes down the ramp, and is at its highest point on the ramp. Point out the connection between the direction of an object's change of velocity and the direction of its acceleration.

DIFFICULTIES AND MAJOR ALTERNATIVE CONCEPTIONS

Many students believe that the acceleration decreases as the cart moves up the incline and assume that it goes to zero at the top. These students will probably incorrectly say that the cart "stops" at its highest point. Some students believe the acceleration goes from negative to positive as it moves up the incline. Others may believe that the acceleration is necessarily in the direction of motion.

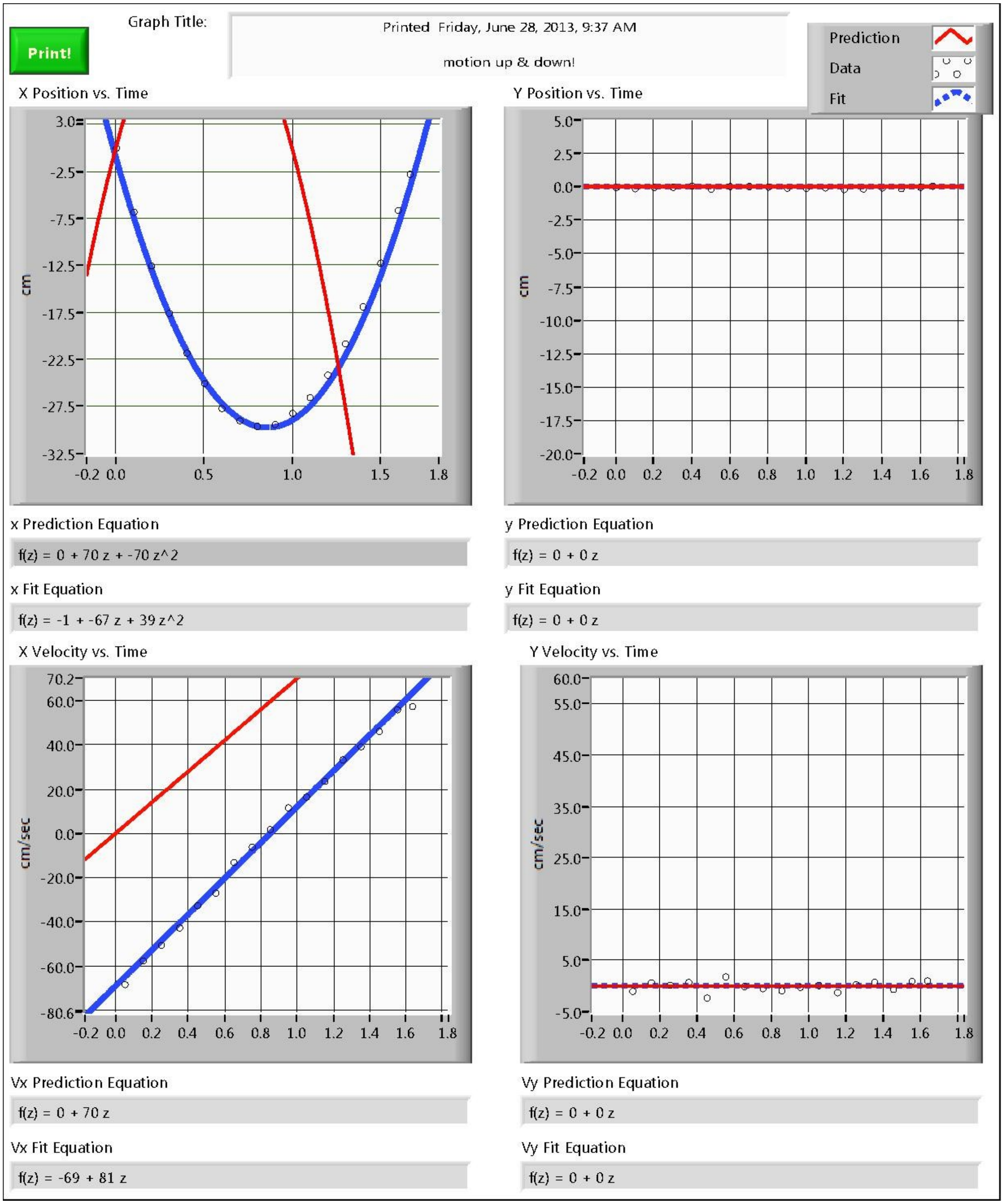
PREDICTION AND WARM-UP QUESTIONS

Constant and identical acceleration for all parts of the motion.

SAMPLE DATA

Inclined angle: $\sin^{-1}(18.0cm/220.0cm)$;

Acceleration: $a=80cm/s^2$.


Print!
Graph Title:
Printed Friday, June 28, 2013, 9:37 AM
motion up & down!
Prediction
Data
Fit
X Position vs. Time
Y Position vs. Time
cm
x Prediction Equation
f(z) = 0 + 70 z + -70 z^2
x Fit Equation
f(z) = -1 + -67 z + 39 z^2
y Prediction Equation
f(z) = 0 + 0 z
y Fit Equation
f(z) = 0 + 0 z
X Velocity vs. Time
Y Velocity vs. Time
cm/sec
Vx Prediction Equation
f(z) = 0 + 70 z
Vx Fit Equation
f(z) = -69 + 81 z
Vy Prediction Equation
f(z) = 0 + 0 z
Vy Fit Equation
f(z) = 0 + 0 z

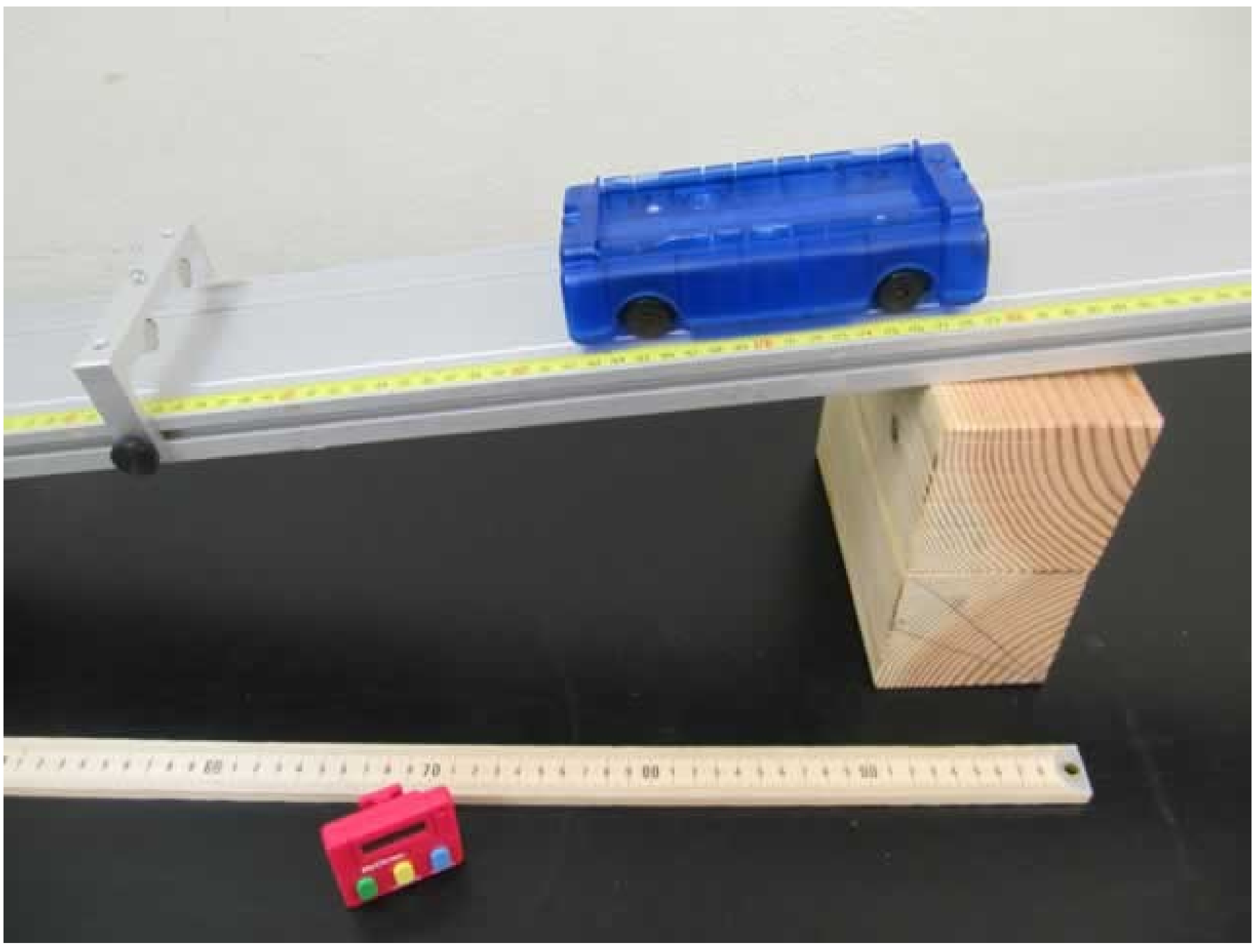
LAB 1, PROBLEM 4: MOTION DOWN AN INCLINE WITH AN INITIAL VELOCITY

PURPOSE

To show students that the acceleration of an object is independent of its velocity.

EQUIPMENT

Track, end stop, card, wooden blocks, meter stick, stopwatch



TEACHING TIPS

- This is a good problem for students who always want to use the origin as a point in their position vs. time graphs.
- Those students who don't yet understand the difference between velocity and acceleration should also find this problem helpful.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The alternative conception here is a faster cart will have a larger acceleration. Another is that the direction of the cart's acceleration is necessarily the same as the direction of its velocity.

PREDICTION AND WARM-UP QUESTIONS

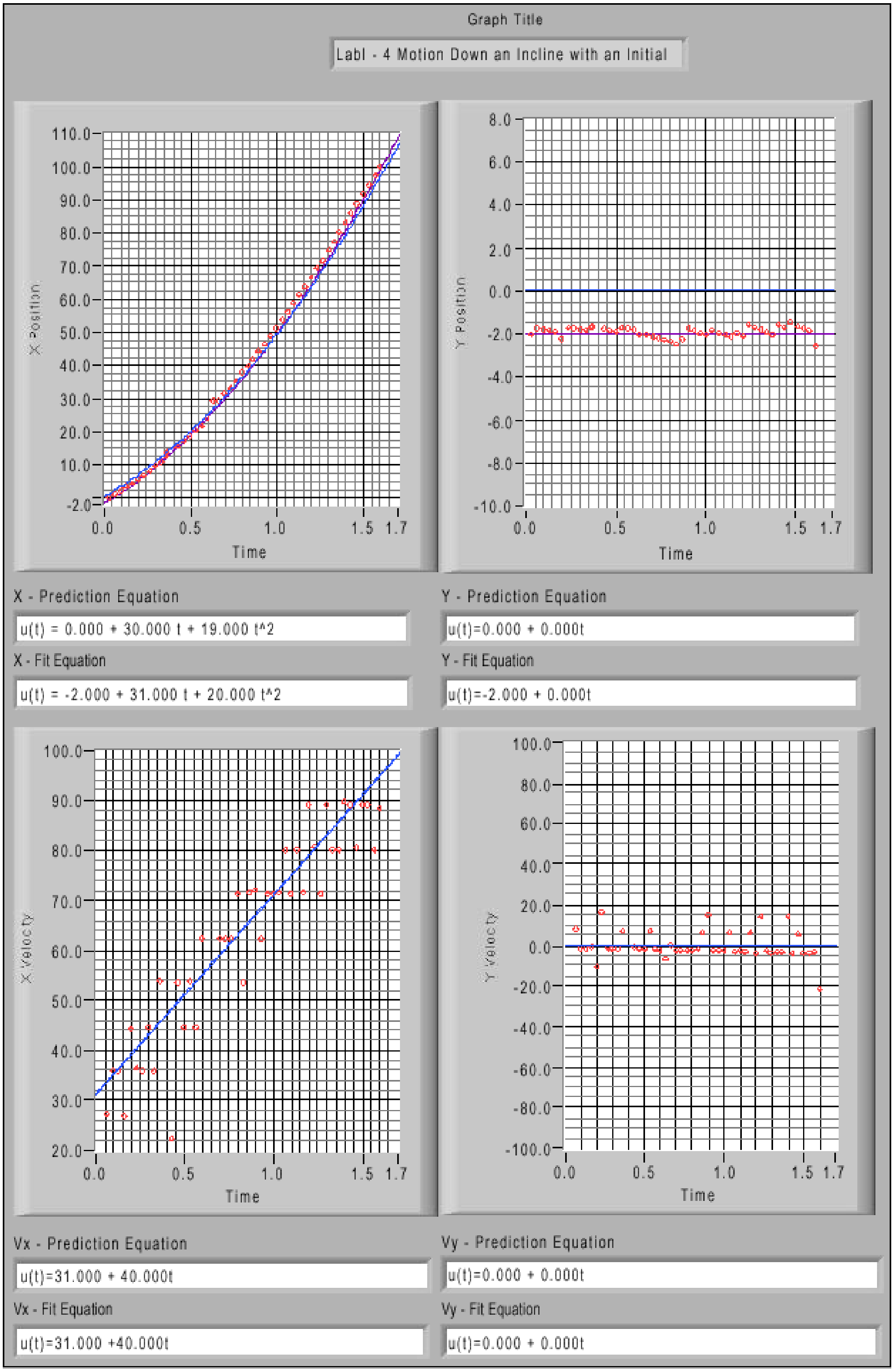
Graph of constant acceleration (the same acceleration as that for a cart released from rest on the same incline).

SAMPLE DATA

Inclined angle: $Sin^{-1}(8.7/220.5)$

Initial velocity: V_0=31cm/s

Acceleration: a=40cm/s^2


Graph Title
Labl - 4 Motion Down an Incline with an Initial
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 30.000 t + 19.000 t^2
X - Fit Equation
u(t) = -2.000 + 31.000 t + 20.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-2.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=31.000 + 40.000t
Vx - Fit Equation
u(t)=31.000 +40.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

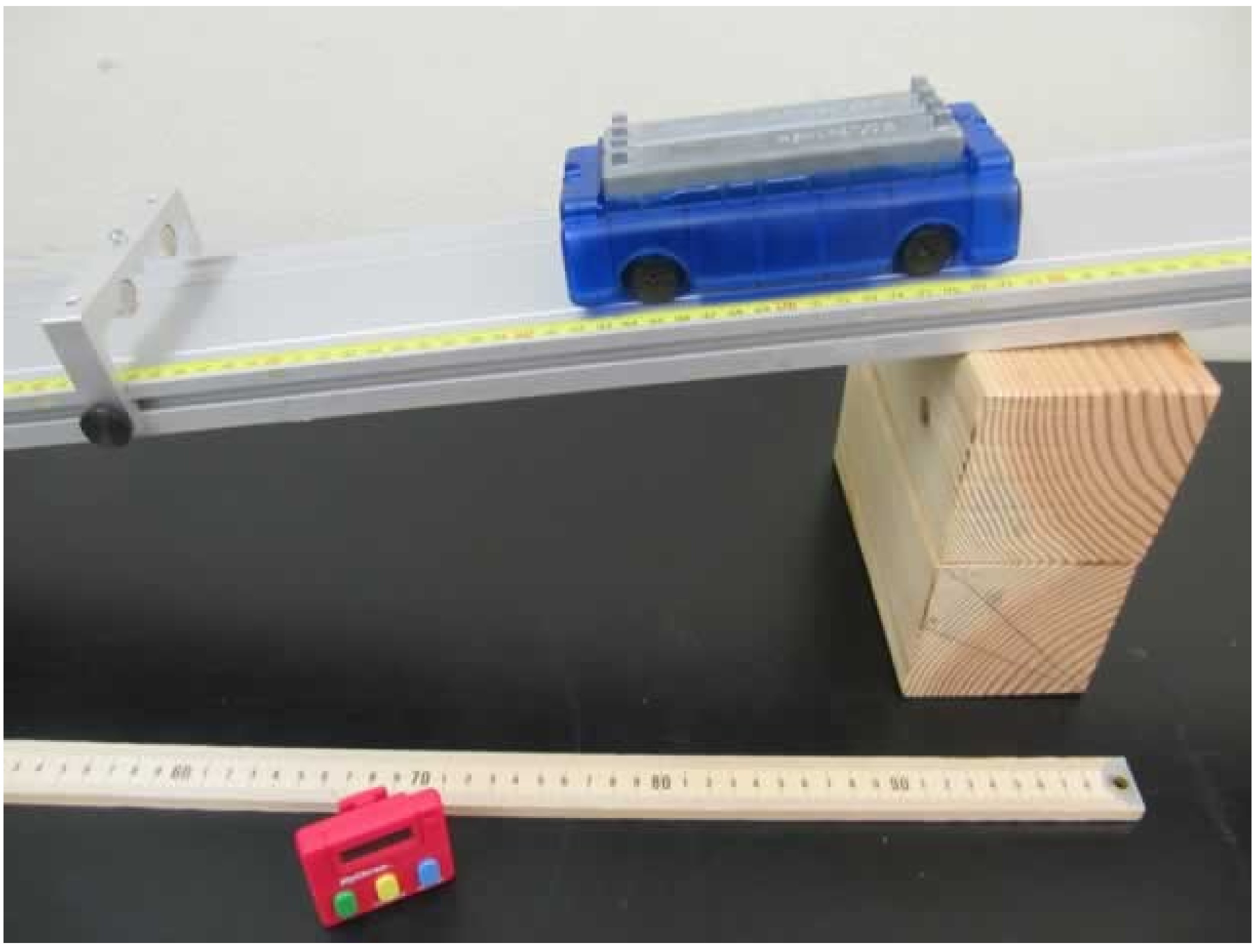
LAB 1, PROBLEM 5: MASS AND MOTION DOWN AN INCLINE

PURPOSE

To show that the acceleration down an incline is independent of the mass of the cart. This is a surprising result!

EQUIPMENT

Track, end stop, cart, cart masses, wooden blocks, meter stick, stopwatch.



TEACHING TIPS

- If there is too much mass placed on the carts, they do not work well because of the friction caused in the bearings. A careful exploration is required to determine what range of mass can be used.
- Try to get them to take data for at least four different cart masses. Many students will only take two movies, especially if the results confirm their preconceptions.

- Emphasize that they should analyze a movie before they take the next one. It will save them time in the long run.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

This problem confronts the common experience that heavier things fall faster. Your students might not make the connection between objects falling down a ramp and objects in free fall, however, so you should point out this connection once they have discovered the mass-independence.

This lab is also not as structured as the previous ones, so if you have a good group, this might be an appropriate extra problem for them.

PREDICTION AND WARM-UP QUESTIONS

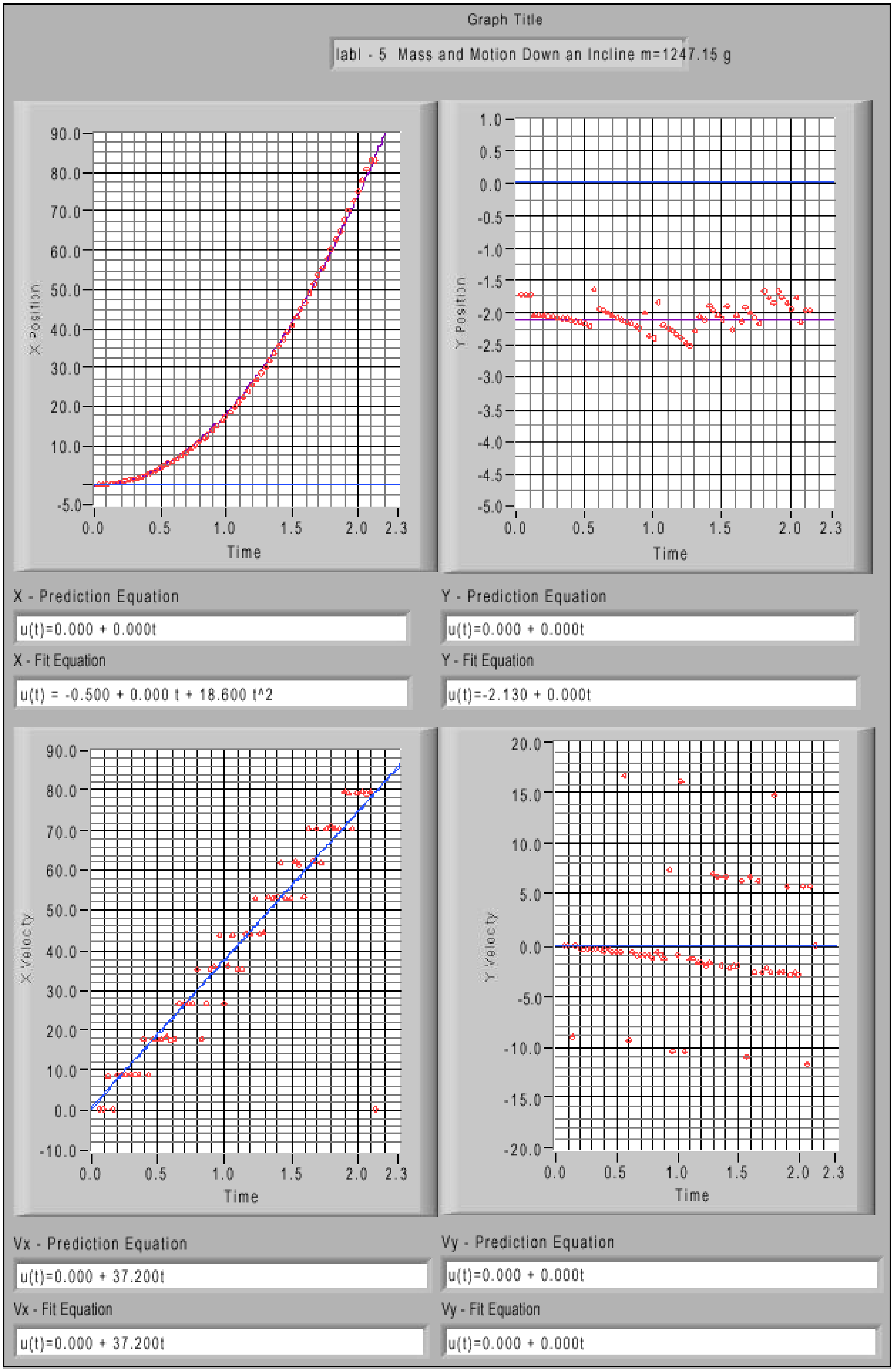
Acceleration is independent of mass.

SAMPLE DATA

Inclined angle: $\sin^{-1}(8.7/220.5)$

Case 1 (data of problem #2): Mass of cart 251.65 g, Acceleration 37.2 cm/s^2

Case 2 (data below): Mass of cart with cart masses 1247.15 g, Acceleration 37.2 cm/s^2



Graph Title
labl - 5 Mass and Motion Down an Incline m=1247.15 g
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = -0.500 + 0.000 t + 18.600 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-2.130 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 37.200t
Vx - Fit Equation
u(t)=0.000 + 37.200t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

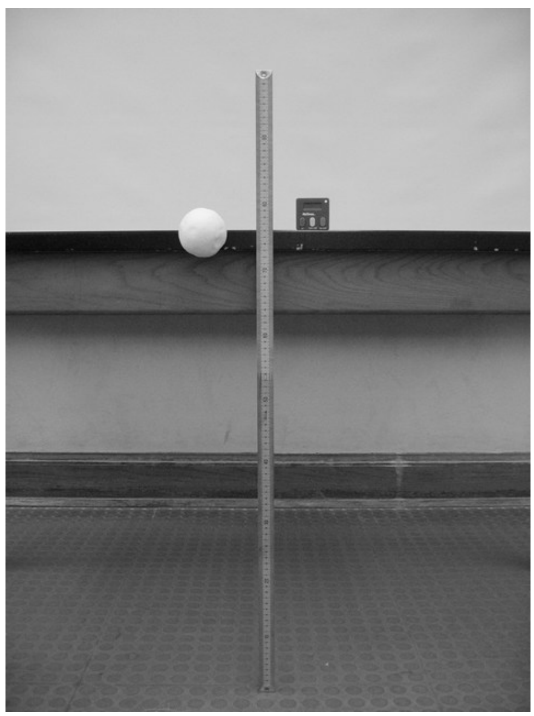
LAB 1, PROBLEM 6: MASS AND THE ACCELERATION OF A FALLING BALL

PURPOSE

- To reinforce the distinctions between velocity and acceleration, position and displacement, and average and instantaneous quantities in the case of constant acceleration.
- To demonstrate the importance of good data-taking and analysis techniques.
- To emphasize the importance of graphical representations of motion.
- To show students the effect of the real world on physics experiments. Specifically, to show how much (or little) air resistance affects the acceleration of a freely falling object.

EQUIPMENT

Stopwatch, meter stick, assorted balls.



TEACHING TIPS

- You and your students may find that the answer to this problem is different from in the text; namely, that heavier objects fall faster. The effect is small for most of the balls, but pairs with extreme mass differences, or the whiffle ball, may have accelerations sufficiently different to be noticeable. You should be sure that your students understand that this is a small effect for most common objects and is caused by the interaction of the object with the air. You should be sure that this result does not reinforce the alternative conception that heavier things "naturally" fall faster. To make this "mass effect" clearer to you, we include the following equations:

$$F_t = W_t - F_{Air} \qquad F_s = W_s - F_{Air}$$

$$a_t = g - \frac{F_{Air}}{m_t} \qquad a_s = g - \frac{F_{Air}}{m_s}$$

t and s stand for tennis ball and Styrofoam ball, respectively (we use these as an example.) F is the total force on the ball ($= ma$), W is the weight of the ball ($= mg$), and F_{Air} is the air-resistance force, which is the same for both balls if they are the same size and shape. a and m are the acceleration and mass of the ball, and g is the gravitational acceleration. Since $m_t > m_s$ the acceleration of the tennis ball will be greater than that of the Styrofoam ball. You **should not** have this discussion with your students at this time, as they have not yet learned about forces. You may want to keep the above explanation in mind for future class discussions.

- Some students may be helped by looking at the limiting values — what would be the acceleration of an infinitely heavy/light object? You can use the common example of a rock as opposed to a feather. What would be the acceleration if there were no air?
- Whatever approach you decide to use, its effectiveness will be enhanced if you listen to what the student believes. Let your students do the thinking as you ask questions to bring them to the correct conclusion.
- Encourage your students to use significant mass differences. Ask them what a significant difference is.
- Parallax must be taken into account; this is why the students are asked to use the object in motion to calibrate their computers. Shadows and image resolution may prevent an accurate calibration from the balls in flight. In this case, the students should put an object of known length in the plane of motion.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The students may display the same alternative conceptions in this problem that they did in the first lab. Some common alternative conceptions are that heavier masses fall faster because they weigh more, or, although the acceleration is the same (g), the heavier mass will still fall faster, or since gravity pulls on a heavier object more than a lighter object (true) the heavier object has the greater acceleration (false). A common graphical misconception is that if the position-versus-time graph is a curve, then the trajectory of the object is that same curve. Here students can observe (especially if you point it out) that the object certainly follows a straight path even though the position-versus-time graph is a curve.

PREDICTION AND WARM UP QUESTIONS

Neglecting air-resistance, all the balls should fall with the same acceleration (g).

SAMPLE DATA

The printouts for the measurements of only the baseball and foam ball are included.

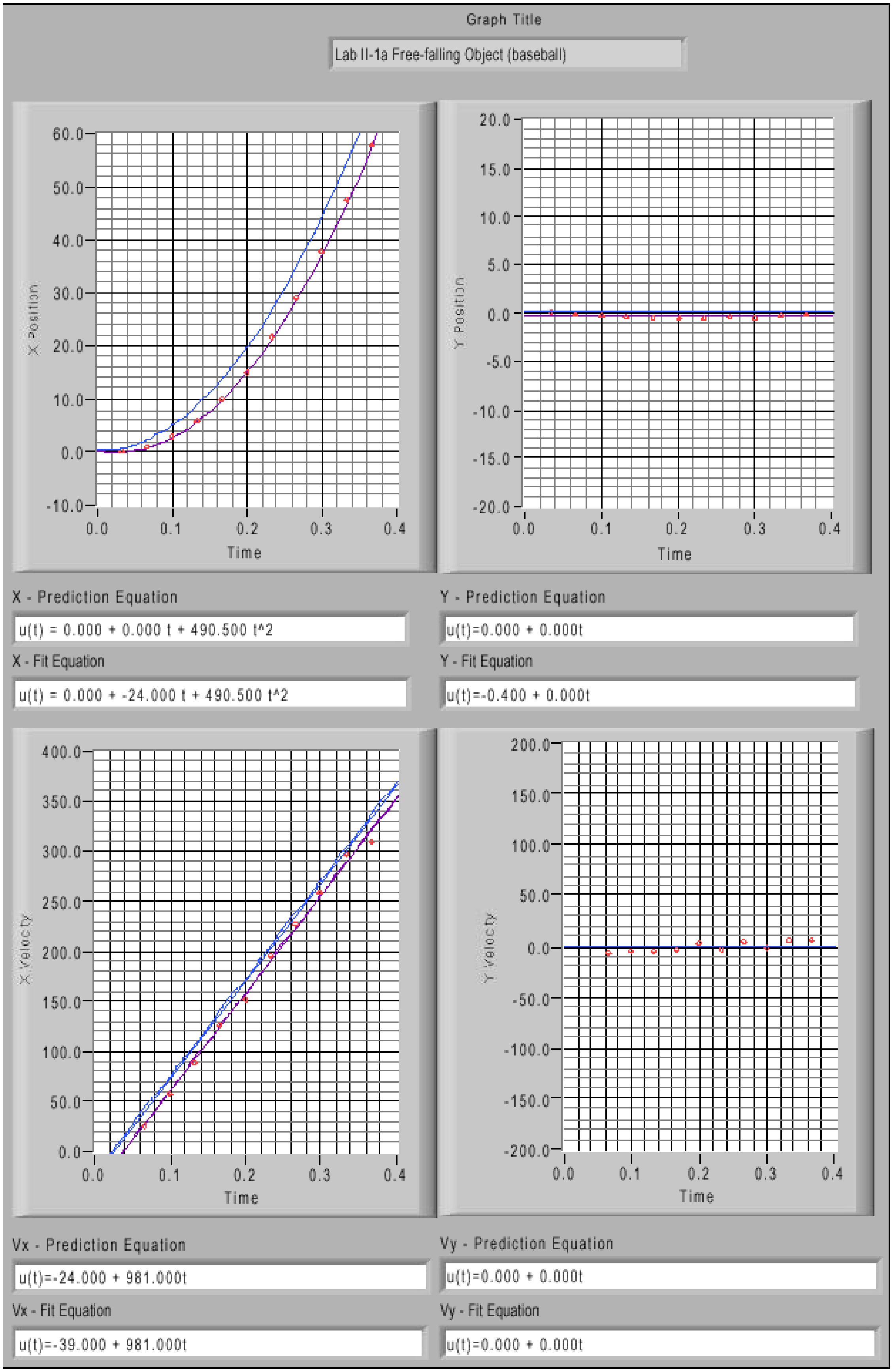
baseball: mass = 144.50g, diameter = 7.40cm

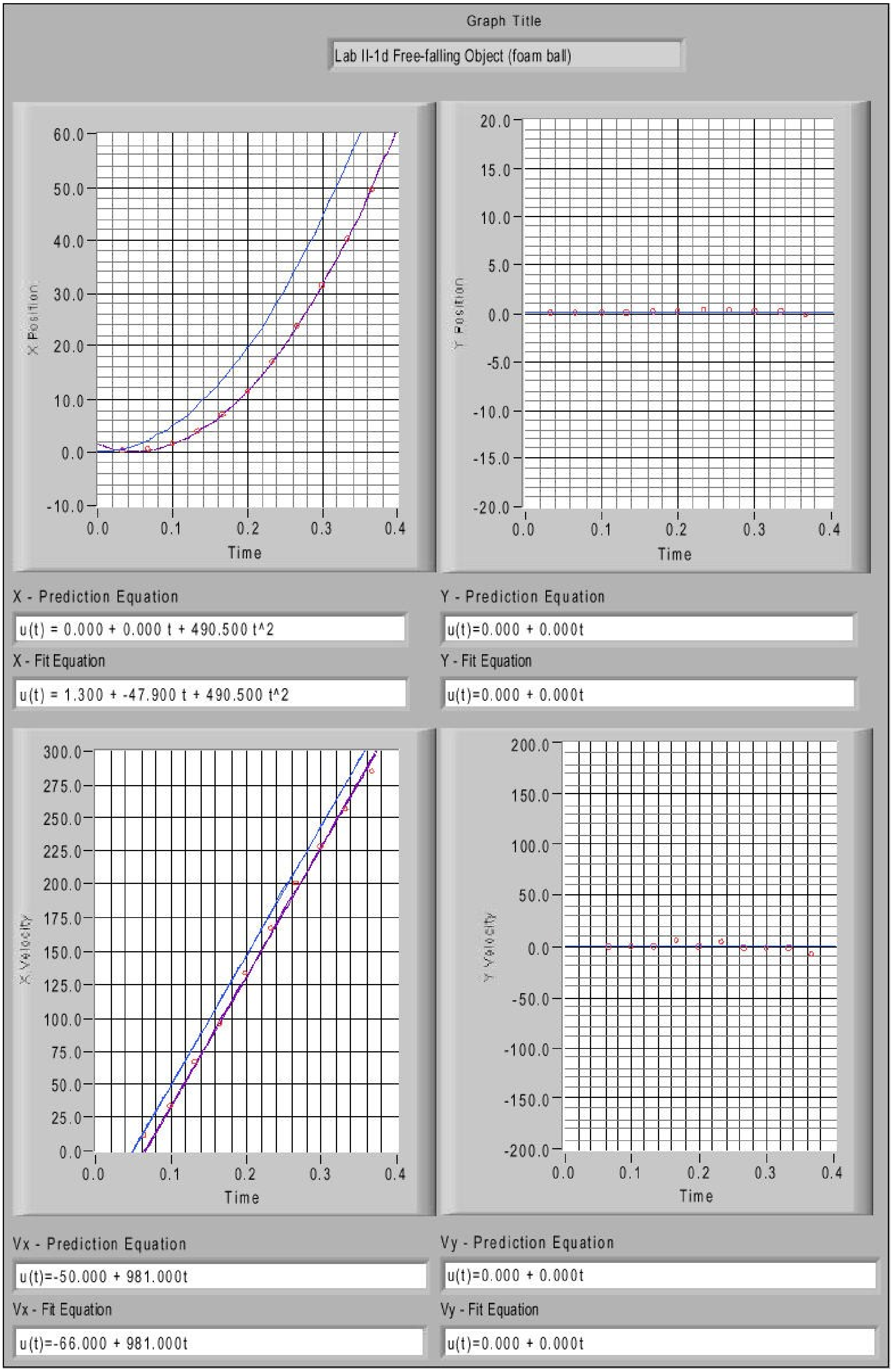
tennis ball: mass = 60.00g, diameter = 6.71cm

street hockey ball: mass = 47.49g, diameter = 6.56cm

foam ball: mass = 11.93g, diameter = 6.95cm

The free-fall acceleration of all four balls (with different masses) is 9.81m/s^2.


Graph Title
Lab II-1a Free-falling Object (baseball)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 0.000 t + 490.500 t^2
X - Fit Equation
u(t) = 0.000 + -24.000 t + 490.500 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-0.400 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-24.000 + 981.000t
Vx - Fit Equation
u(t)=-39.000 + 981.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab II-1d Free-falling Object (foam ball)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 0.000 t + 490.500 t^2
X - Fit Equation
u(t) = 1.300 + -47.900 t + 490.500 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-50.000 + 981.000t
Vx - Fit Equation
u(t)=-66.000 + 981.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

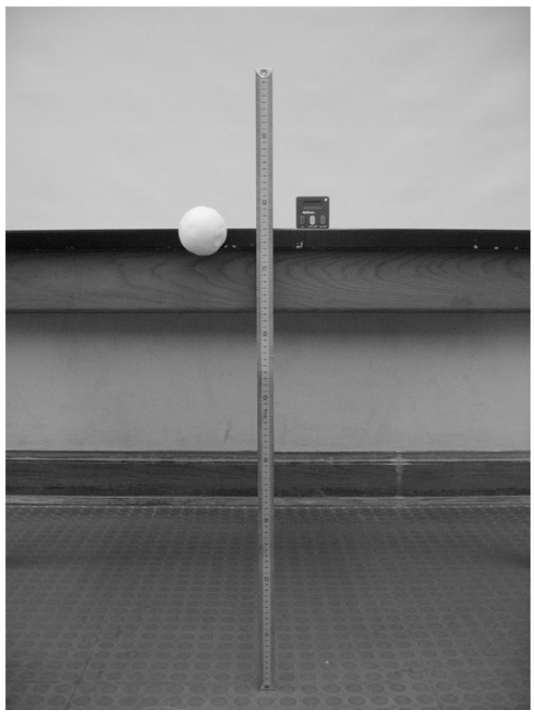
LAB 1, PROBLEM 7: ACCELERATION OF A BALL WITH AN INITIAL VELOCITY

PURPOSE

- To reinforce the distinction between velocity and acceleration.
- To reinforce the relationship between these quantities in the case of constant acceleration.
- To show students that free-fall acceleration is independent of the initial velocity.

EQUIPMENT

Stopwatch, meter stick, assorted balls.



TEACHING TIPS

- This problem is very similar to Lab 1, Problem #4 (Motion Down an Incline with an Initial Velocity). There is no need for all students to complete this problem. It is meant only for those students who are still having trouble with the difference between velocity and acceleration.
- This problem is a bit tough to do because it is difficult to get a wide range of initial velocities for the movies.
- The students should try to find the initial velocity of the ball by analyzing the motion of the ball while it is still in their hand. Make sure that they are aware of this and hold the

ball so that they can see it in their movie. This is especially good for those students who still believe that the hand must affect the acceleration of the ball.

- Because of the two considerations directly above, it is essential that the students take some time to explore how they are going to make their movies. We expect them to take many more bad than good movies!

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The major alternative conception here is that the ball with the largest initial velocity will have the largest acceleration or that the hand somehow "impresses" acceleration on the ball.

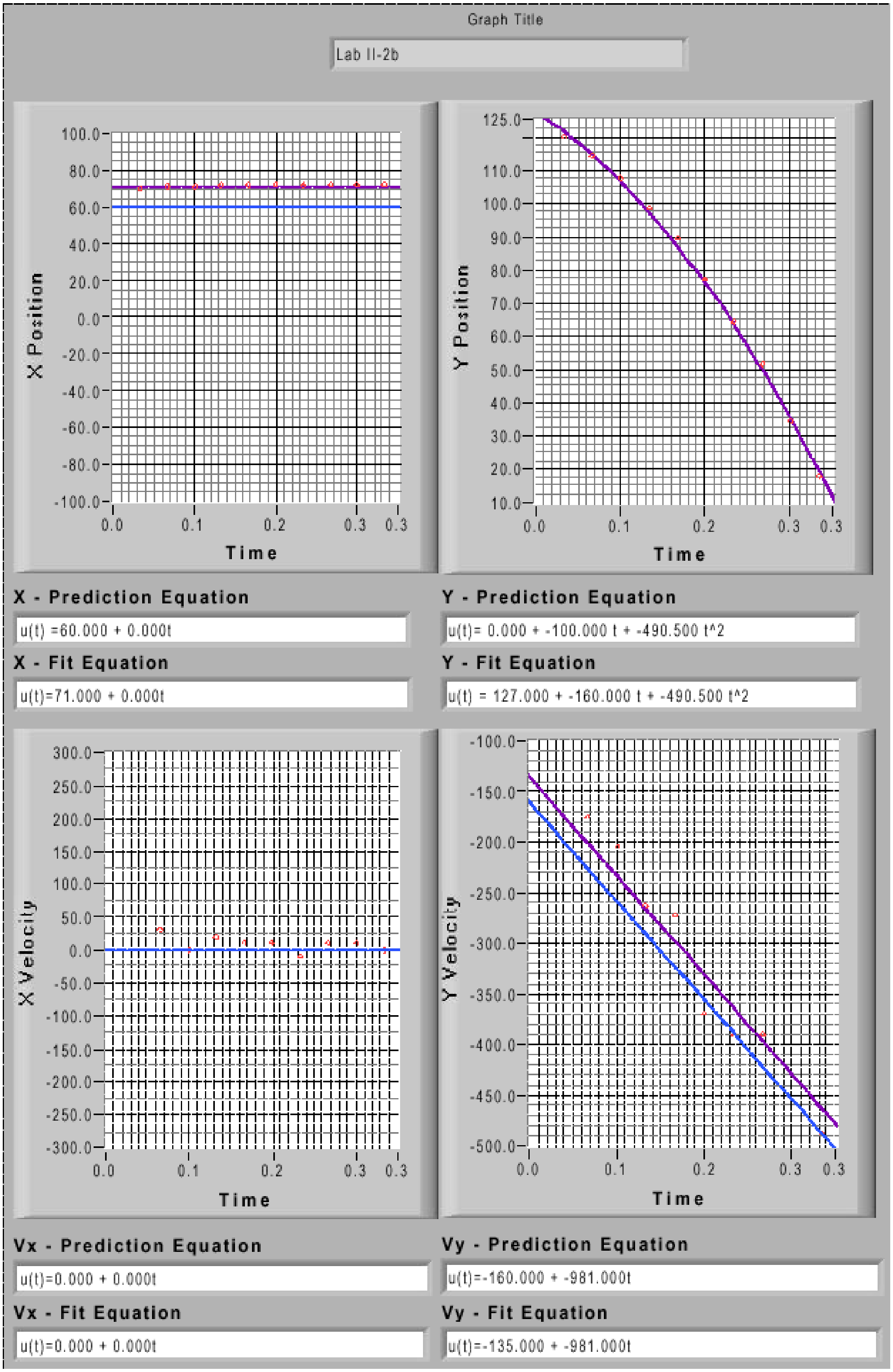
PREDICTION AND WARM UP QUESTIONS

Acceleration is independent of initial velocity ($a = g$).

SAMPLE DATA

Only one printout for the case of a nonzero initial velocity is included.

Using street hockey ball: mass = 47.49g, diameter = 6.56cm. For three different initial speeds, accelerations are all 9.81m/s^2.


Graph Title
Lab II-2b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) =60.000 + 0.000t
X - Fit Equation
u(t)=71.000 + 0.000t
Y - Prediction Equation
u(t)= 0.000 + -100.000 t + -490.500 t^2
Y - Fit Equation
u(t) = 127.000 + -160.000 t + -490.500 t^2
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t)=0.000 + 0.000t
Vy - Prediction Equation
u(t)=-160.000 + -981.000t
Vy - Fit Equation
u(t)=-135.000 + -981.000t

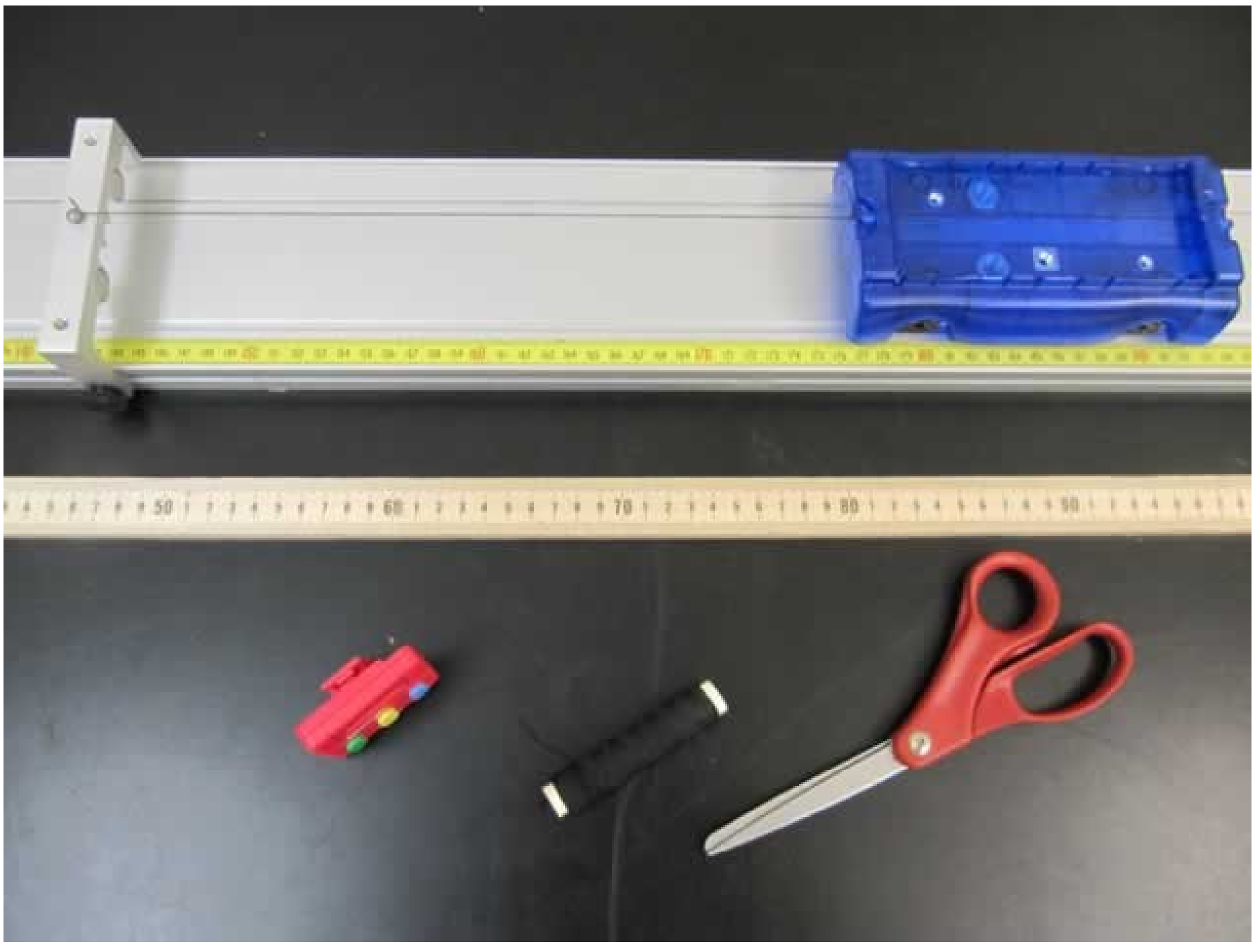
LAB 1 PROBLEM 8: MOTION ON A LEVEL SURFACE WITH AN ELASTIC CORD

PURPOSE

To show students an example of motion which is not constant acceleration.

EQUIPMENT

Track, end stop, cart, meter stick, stopwatch, scissors, elastic cord.



TEACHING TIPS

- Be sure the students recognize that $a_{avg} \neq a_{inst}$, in this case.
- This problem is good for those students who understand acceleration only in the case of constant acceleration. Since the elastic doesn't behave like a Hooke's-law spring when it is over-extended, the resulting acceleration is very interesting.
- A careful exploration is required to determine what range of stretching can be used.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

This lab demonstrates that there is more than just constant acceleration in the world. If students insist on using an unjustified "cookbook" technique (e.g., the average velocity = instantaneous velocity at the center of the time interval or $x(t) = x_o + v_o t + \frac{1}{2} a t^2$) and believe that it is always true, this problem will help you point out their mistake.

PREDICTION AND WARM-UP QUESTIONS

Since your students will not have yet encountered the concepts of forces or Hooke's law, under no circumstances should you discuss these ideas with them. It is sufficient for them to be able to qualitatively describe how the acceleration will change as the elastic becomes unstretched. However, here is the result obtained using Hooke's law, for your own interest:

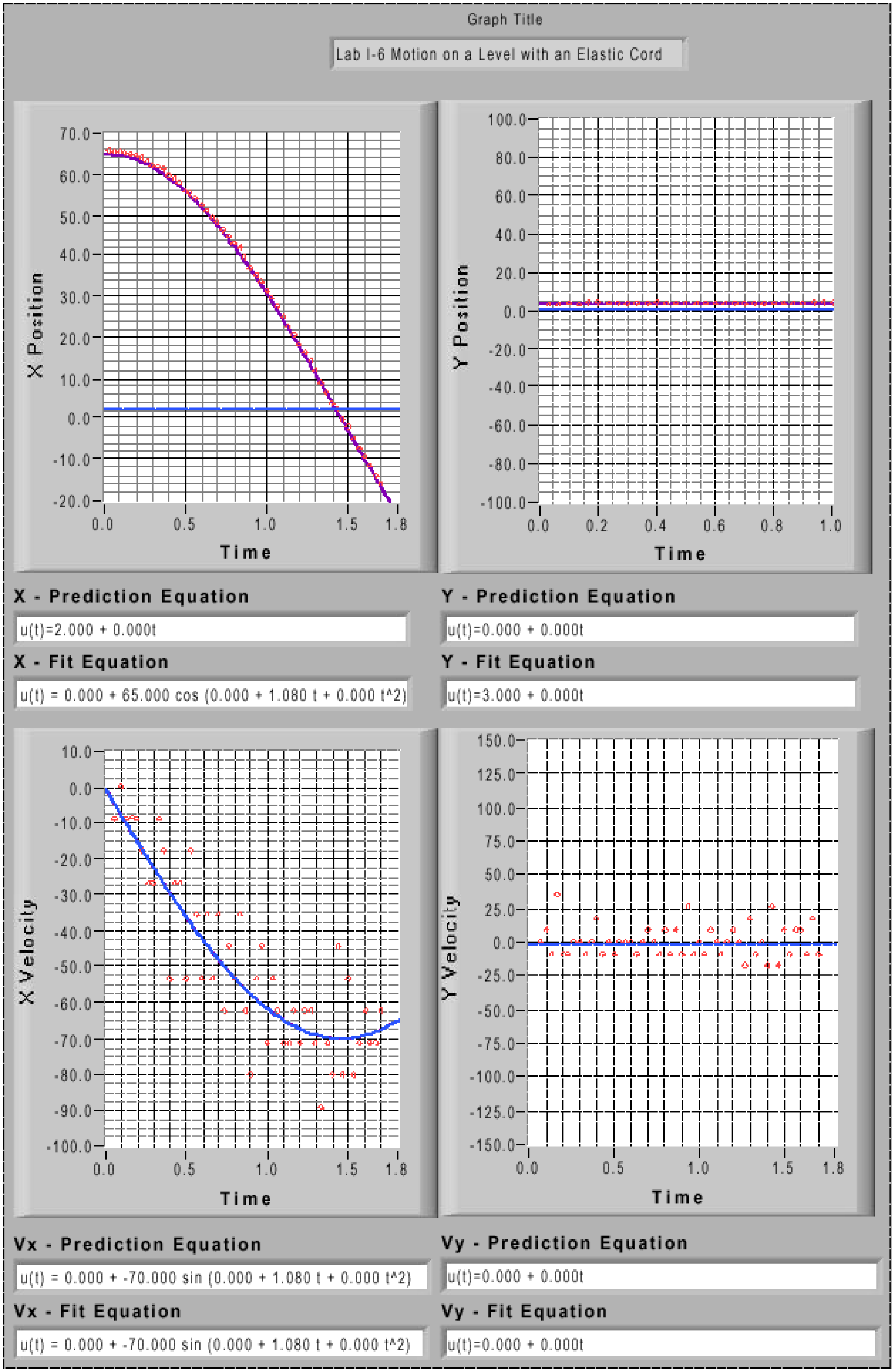
$$a = \frac{Ak}{m}\cos\left(t\sqrt{\frac{k}{m}}\right), \text{ when } 0 \le t \le \frac{\pi}{2}\sqrt{\frac{m}{k}}$$

$$a = 0, \text{ when } t \ge \frac{\pi}{2}\sqrt{\frac{m}{k}}$$

A is the initial extension in the elastic, k is the spring constant for the elastic cord, m is the mass of the cart, and the acceleration a is directed along the track towards the end-stop.

SAMPLE DATA

The acceleration is changing with time.


Graph Title
Lab I-6 Motion on a Level with an Elastic Cord
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=2.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 65.000 cos (0.000 + 1.080 t + 0.000 t^2)
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -70.000 sin (0.000 + 1.080 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -70.000 sin (0.000 + 1.080 t + 0.000 t^2)
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

TA Lab Evaluations

Physics 1301 Lab 1: Description of Motion in One Dimension

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to labhelp@physics.umn.edu, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

Do you have additional comments regarding student learning and these labs?

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

Lab Room

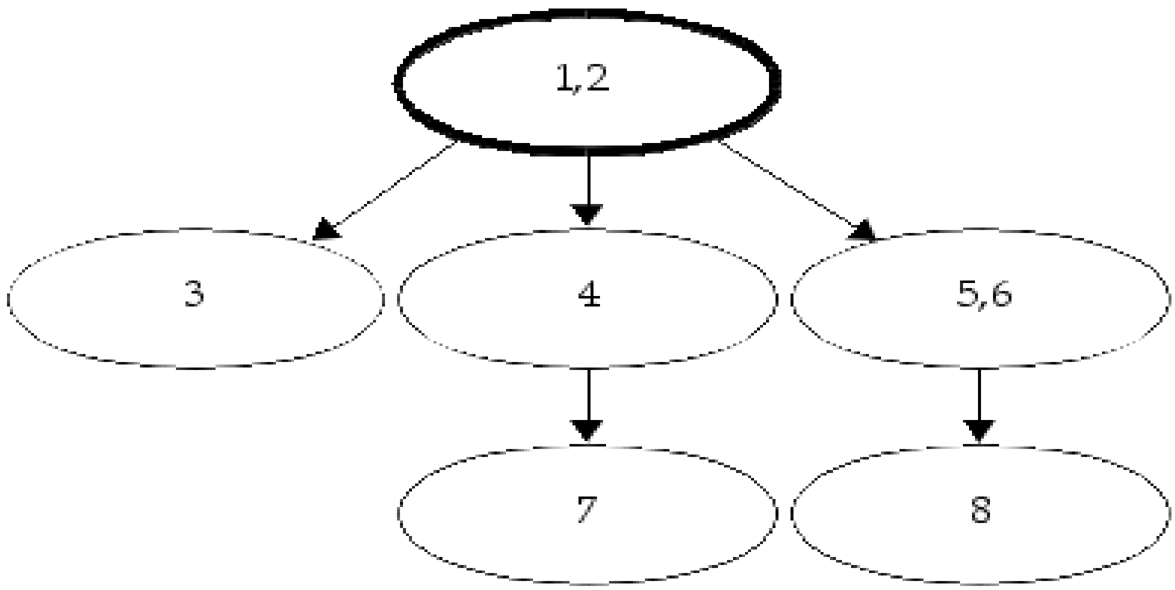
Was the room kept neat and clean by your class and other classes? (circle one) yes / no

Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

LABORATORY 2: CONSERVATION OF MOMENTUM AND ENERGY

This laboratory contains eight problems. It teaches the conservation of both energy and momentum. You will need to be very aware of what material is being taught in lecture so that



your students are not required to invoke any concepts with which they are not yet familiar to complete the problems. If this does happen, do the best you can, and try to be aware in advance so that you can recommend in the preceding week that students read relevant portions of the text.

It is particularly important to note that your students have not yet been taught about forces. You may, therefore, need to come back to some of these problems later in the semester, e.g. problem 8.

Problems 1 and 2 teach students about the difference between energy and momentum, and about the situations in which each is conserved. You are highly recommended to do these labs, and to do them early.

GENERAL TEACHING TIPS

- These problems may precede the lecture by a few days. Resist the urge to lecture on the topics. These labs can serve as a good introduction to the lectures. If your students have the habit of preparing for lab, they should be able to complete these problems.
- **Energy efficiency** is defined at the beginning of Lab 2, Problem 1 as the ratio of the final kinetic energy of the system to the initial kinetic energy. We use this language so that students can deal with real systems.

- Remember to make sure that every group member gets a turn using the computer. If you do not intervene, there will be students who have not even touched the computer at the end of the semester.

BY THE END OF THIS LAB, STUDENTS SHOULD BE ABLE TO

- Use the concept of energy in describing the interactions of objects in contact with each other
- Understand the importance of defining a system when using the principle of conservation of energy.
- Identify different types of energy when applying the energy conservation principle to real systems.

THINGS TO CHECK OUT BEFORE THIS LAB

- Check the wheels on the carts: make sure they spin freely.
- By watching several collisions, estimate how much energy is dissipated in a bumper-to-bumper collision between two carts. This will help you determine if a group has a serious problem understanding the physics.
- Make sure you know which end of a cart has magnets on it.
- Too forceful a collision will cause the carts to jump off the track. Play around with different initial velocities so you can guide students to avoid this effect.
- Practice Problem #5's collision with the end stop.

LAB 2, PROBLEM 1: COLLISIONS WHEN OBJECTS STICK TOGETHER

PURPOSE

To study inelastic collisions and reinforce the concept that momentum is always conserved. Also, to investigate the difference between energy and momentum, noting that though total energy is always conserved, kinetic energy is not in an inelastic collision.

EQUIPMENT

Track, end stops, carts, meter stick, stopwatch

TEACHING TIPS

1. Remember to warn your students to avoid having their carts jump out of the tracks.

2. Keep the cart velocities reasonable to avoid equipment damage and unaccounted for energy transfers.

3. The students need to analyze movies more than once to determine all velocities involved.

4. This is one of those labs where the more aggressive students in the group tend to use the equipment and the more timid students tend to analyze. Do not let this happen in your groups.

DIFFICULTIES AND MAJOR ALTERNATIVE CONCEPTIONS

Many students do not have different concepts of energy and momentum. They are used interchangeably. The students cannot or do not want to decide in which situations they can most easily apply conservation of energy or conservation of momentum or both. Students still have difficulty with the necessity of defining an appropriate system.

PREDICTION AND WARM-UP QUESTIONS

Final velocity of both carts: $$v' = \frac{m_1 v_1}{m_1 + m_2}$$

Efficiency of collision: $$e = \frac{m_1}{(m_1 + m_2)}$$

where m_1 is the mass of the cart1 initially in motion and m_2 is the mass of the cart2 initially at rest, v_1 is the initial velocity of cart1, and v' is the final velocity of both carts.

Using conservation of momentum, the energy efficiency can be put in terms of the masses alone. With this equation, the collisions can be ranked from most to least efficient: $m_A > m_B$, $m_A = m_B$, $m_A < m_B$.

SAMPLE DATA

1) $m_1 = m_2$

Mass cart 1: m_1 = 503.60g; Mass cart 2: m_2 = 503.12g

INITIAL VELOCITY OF CART 1: v = 52.70 CM/S
PREDICTED FINAL VELOCITY OF BOTH CARTS: v' = 26.36 CM/S
MEASURED FINAL VELOCITY OF BOTH CARTS: v' = 26.50 CM/S
Energy efficiency: e = 0.51

2) $m_1 > m_2$

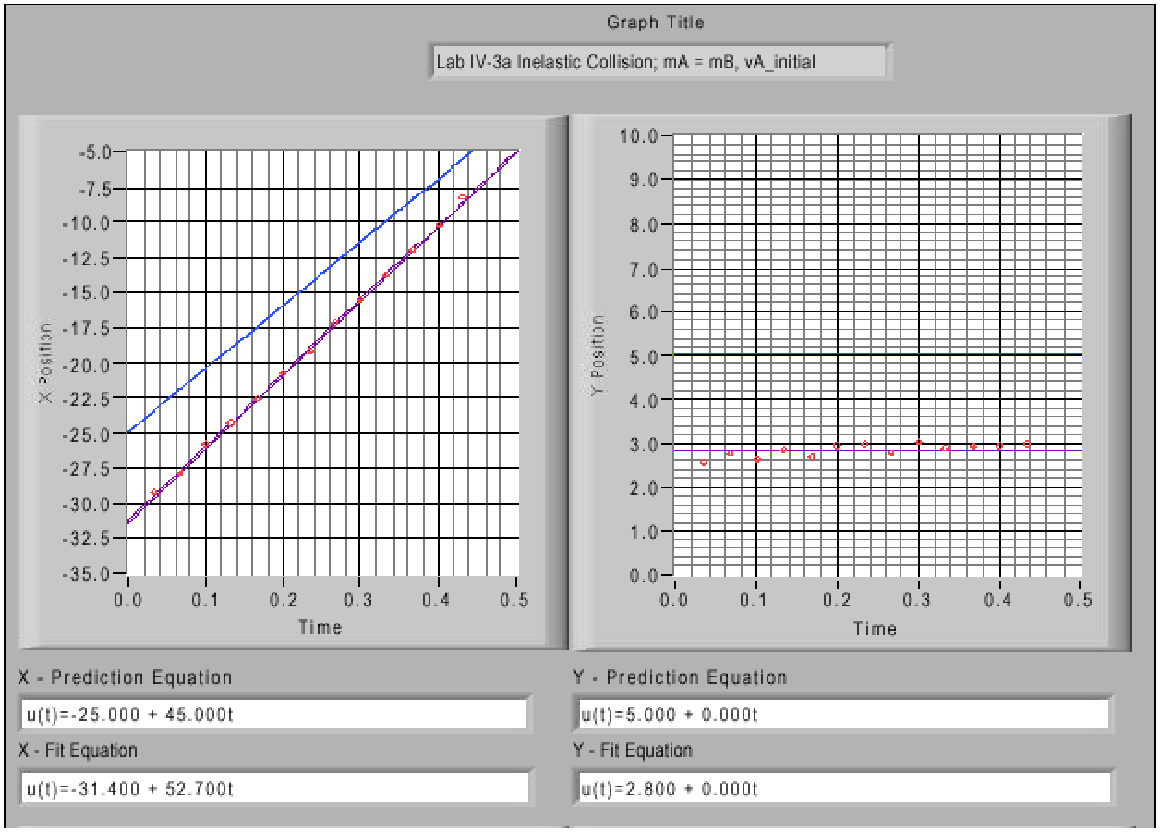
Mass cart 1: m_1 = 753.80g; Mass cart 2: m_2 = 252.92g

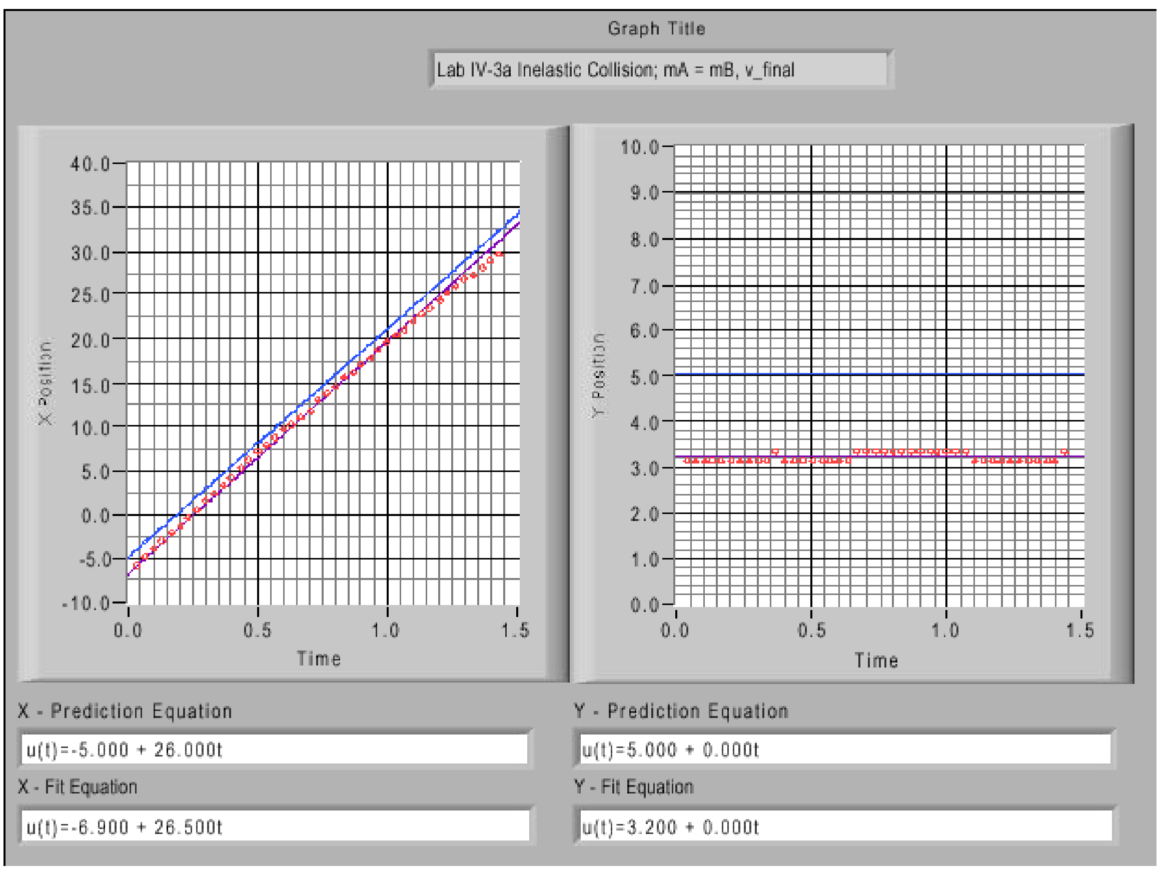
INITIAL VELOCITY OF CART 1: v = 43.10 CM/S
PREDICTED FINAL VELOCITY OF BOTH CARTS: v' = 32.27 CM/S
MEASURED FINAL VELOCITY OF BOTH CARTS: v' = 32.50 CM/S
Energy efficiency: Eff = 0.76

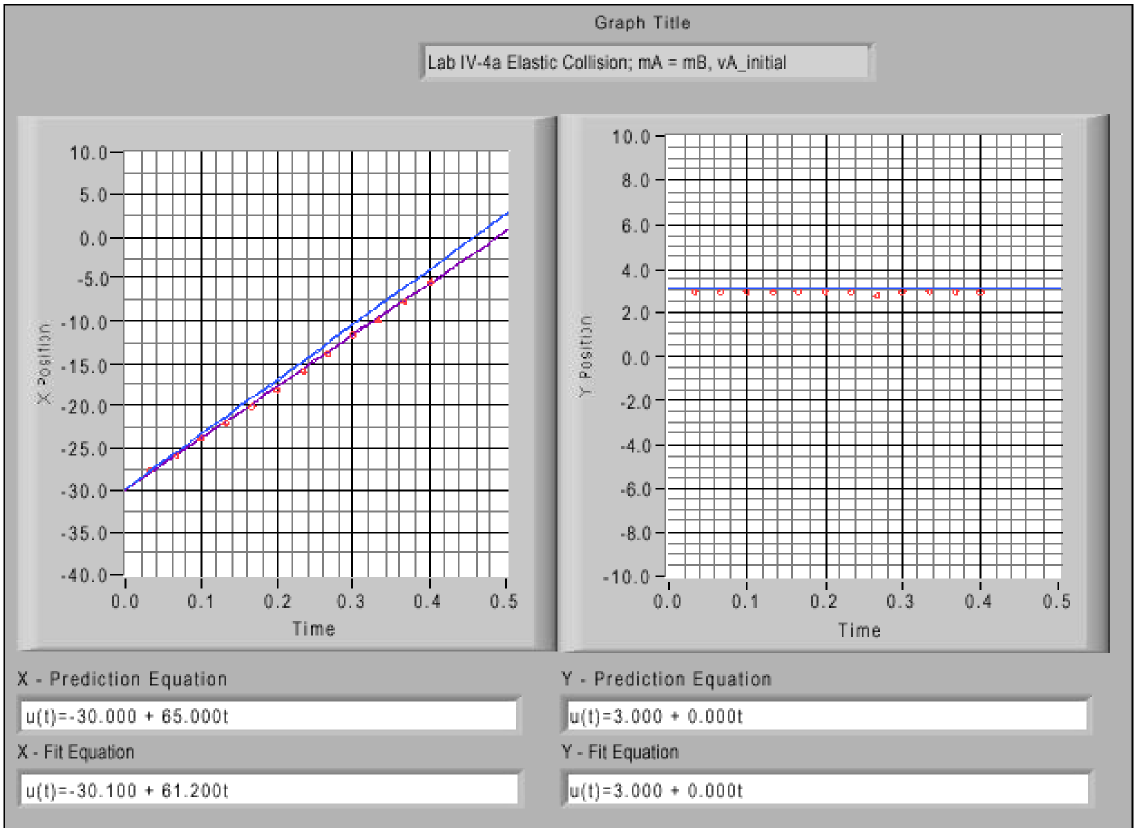
3) $m_1 < m_2$

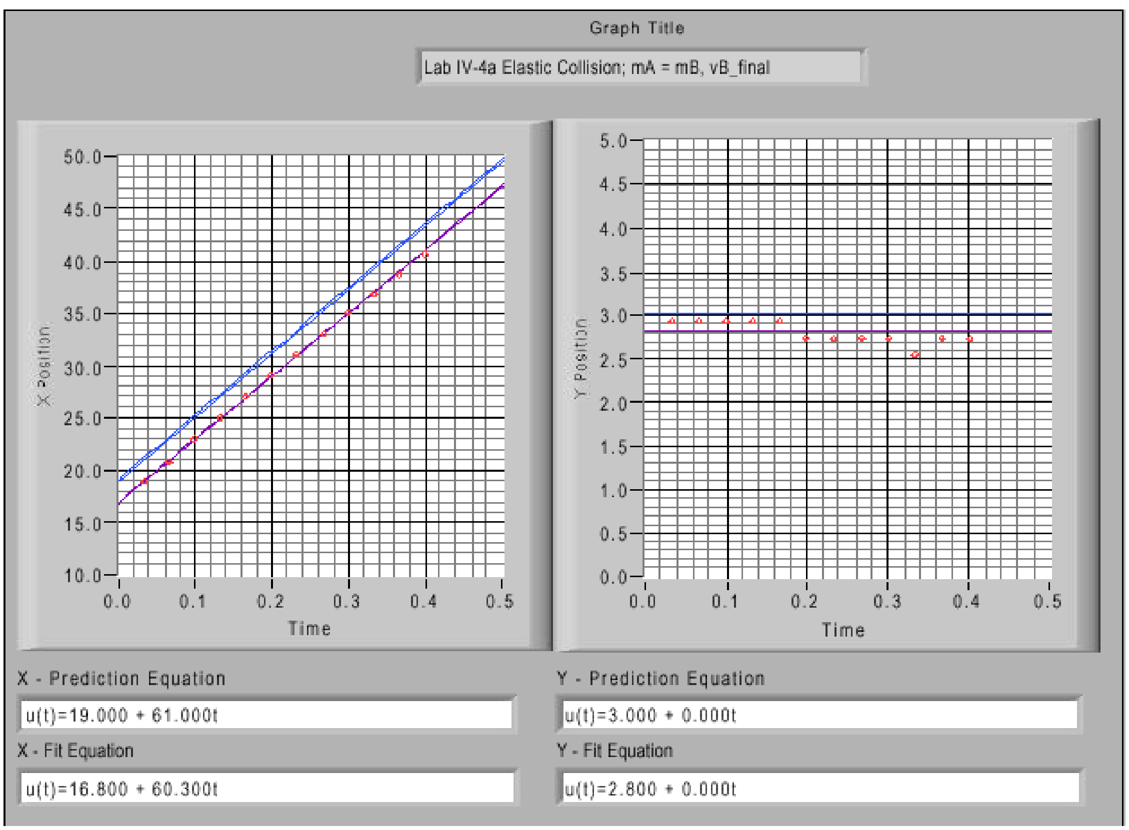
Mass cart 1: m_1 = 252.80g; Mass cart 2: m_2 = 753.92g

INITIAL VELOCITY OF CART 1: v = 91.00 CM/S
PREDICTED FINAL VELOCITY OF BOTH CARTS: v' = 22.85 CM/S
MEASURED FINAL VELOCITY OF BOTH CARTS: v' = 23.80 CM/S
Energy efficiency: Eff = 0.27


Graph Title
Lab IV-3a Inelastic Collision; mA = mB, vA_initial
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-25.000 + 45.000t
X - Fit Equation
u(t)=-31.400 + 52.700t
Y - Prediction Equation
u(t)=5.000 + 0.000t
Y - Fit Equation
u(t)=2.800 + 0.000t


Graph Title
Lab IV-3a Inelastic Collision; mA = mB, v_final
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-5.000 + 26.000t
X - Fit Equation
u(t)=-6.900 + 26.500t
Y - Prediction Equation
u(t)=5.000 + 0.000t
Y - Fit Equation
u(t)=3.200 + 0.000t


Graph Title
Lab IV-4a Elastic Collision; mA = mB, vA_initial
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-30.000 + 65.000t
X - Fit Equation
u(t)=-30.100 + 61.200t
Y - Prediction Equation
u(t)=3.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t


Graph Title
Lab IV-4a Elastic Collision; mA = mB, vB_final
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=19.000 + 61.000t
X - Fit Equation
u(t)=16.800 + 60.300t
Y - Prediction Equation
u(t)=3.000 + 0.000t
Y - Fit Equation
u(t)=2.800 + 0.000t

Lab 2, Problem 2: Collisions When Objects Bounce Apart

Purpose

To study elastic collisions and reinforce the concept that momentum is always conserved. Also, to investigate the difference between energy and momentum, and compare the change in kinetic energy between elastic and inelastic collisions.

Equipment

Track, end stops, carts, meter stick, stopwatch

Teaching Tips

1. The solution for the final velocities of both carts are quadratic due to the extra efficiency term. So be aware that mathematically this prediction is very messy. The students have a very hard time with this prediction.
2. Remember to warn your students to avoid having their carts jump out of the tracks.

3. Keep the cart velocities reasonable to avoid equipment damage and unaccounted for energy transfers.

4. The students need to analyze movies more than once to determine all velocities involved.

5. This is one of those labs where the more aggressive students in the group tend to use the equipment and the more timid students tend to analyze. Do not let this happen in your groups.

DIFFICULTIES AND MAJOR ALTERNATIVE CONCEPTIONS

Many students do not have different concepts of energy and momentum. They are used interchangeably. The students cannot or do not want to decide in which situations they can most easily apply conservation of energy or conservation of momentum or both. Students still have difficulty with the necessity of defining an appropriate system.

PREDICTION AND WARM-UP QUESTIONS

Efficiency of collisions: $$e = \frac{m_1 v_1^2 + m_2 v_2^2}{m_1 v_0^2}$$

Final velocities:

$$v_1 = \frac{\frac{m_1}{m_2} \pm \sqrt{e\left(1 + \frac{m_1}{m_2}\right) - \frac{m_1}{m_2}}}{\left(1 + \frac{m_1}{m_2}\right)} v_0$$

$$v_2 = \frac{1 \mp \sqrt{1 - (1 - e)\left(1 + \frac{m_1}{m_2}\right)}}{\left(1 + \frac{m_2}{m_1}\right)} v_0$$

where m_1 is the mass of cart1 initially in motion, m_2 is the mass of cart2 initially at rest, v_0 is the initial velocity of cart1, v_1 is the final velocity of cart1, v_2 is the final velocity of cart2, and e is the efficiency of the magnetic bumper. The results for final velocity are greatly simplified if efficiency can be assumed to be ~1.

SAMPLE DATA

1) $m_1 = m_2$

Mass cart 1: m_1 = 503.60g; Mass cart 2: m_2 = 503.12g

INITIAL VELOCITY OF CART 1: V = 61.20 CM/S
Energy efficiency: Eff = 0.97

PREDICTED FINAL VELOCITY OF CART 1: V_1' = 0.97 CM/S
MEASURED FINAL VELOCITY OF CART 1: V_1' = 0.00 CM/S
Predicted final velocity of cart 2: v_2' = 60.29 cm/s

Measured final velocity of cart 2: v_2' = 60.30 cm/s

2) $m_1 > m_2$

Mass cart 1: m_1 = 753.80g; Mass cart 2: m_2 = 252.92g

INITIAL VELOCITY OF CART 1: V = 62.80 CM/S
Energy efficiency: Eff = 1.00

PREDICTED FINAL VELOCITY OF CART 1: V_1' = 31.27 CM/S
MEASURED FINAL VELOCITY OF CART 1: V_1' = 32.80 CM/S
Predicted final velocity of cart 2: v_2' = 93.97 cm/s

Measured final velocity of cart 2: v_2' = 92.40 cm/s

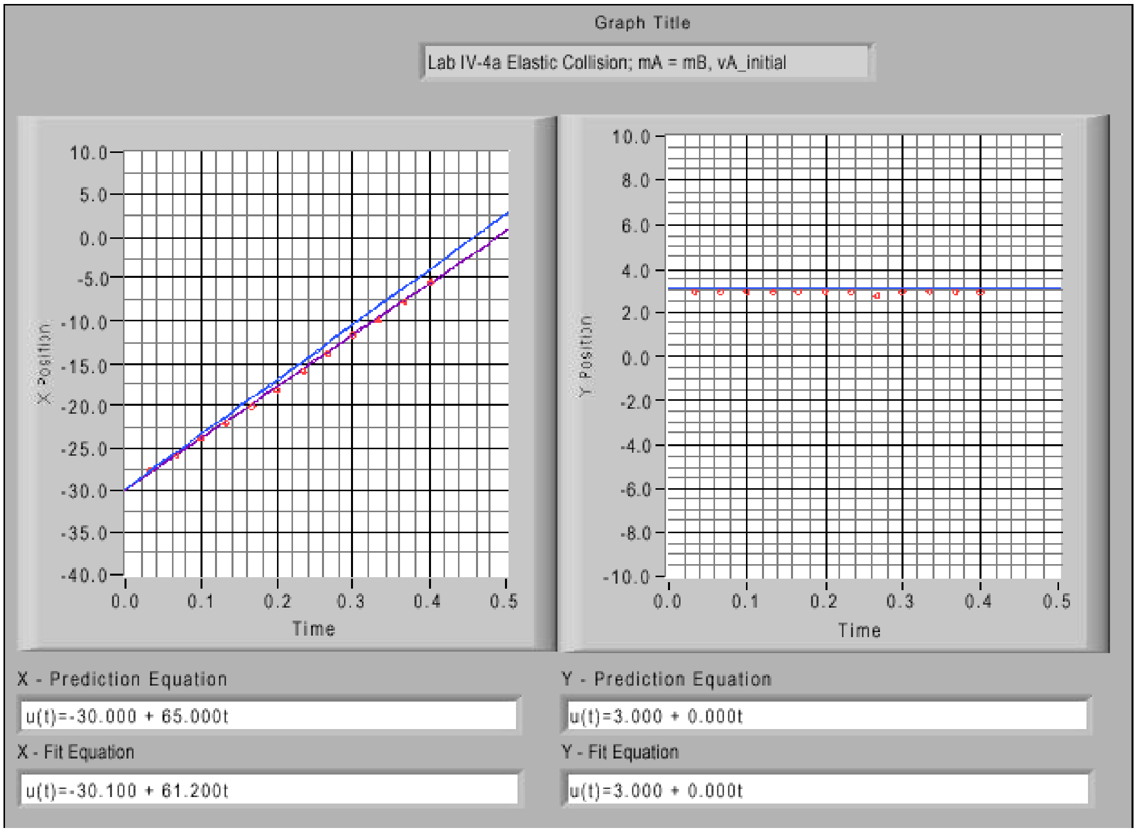
3) $m_1 < m_2$

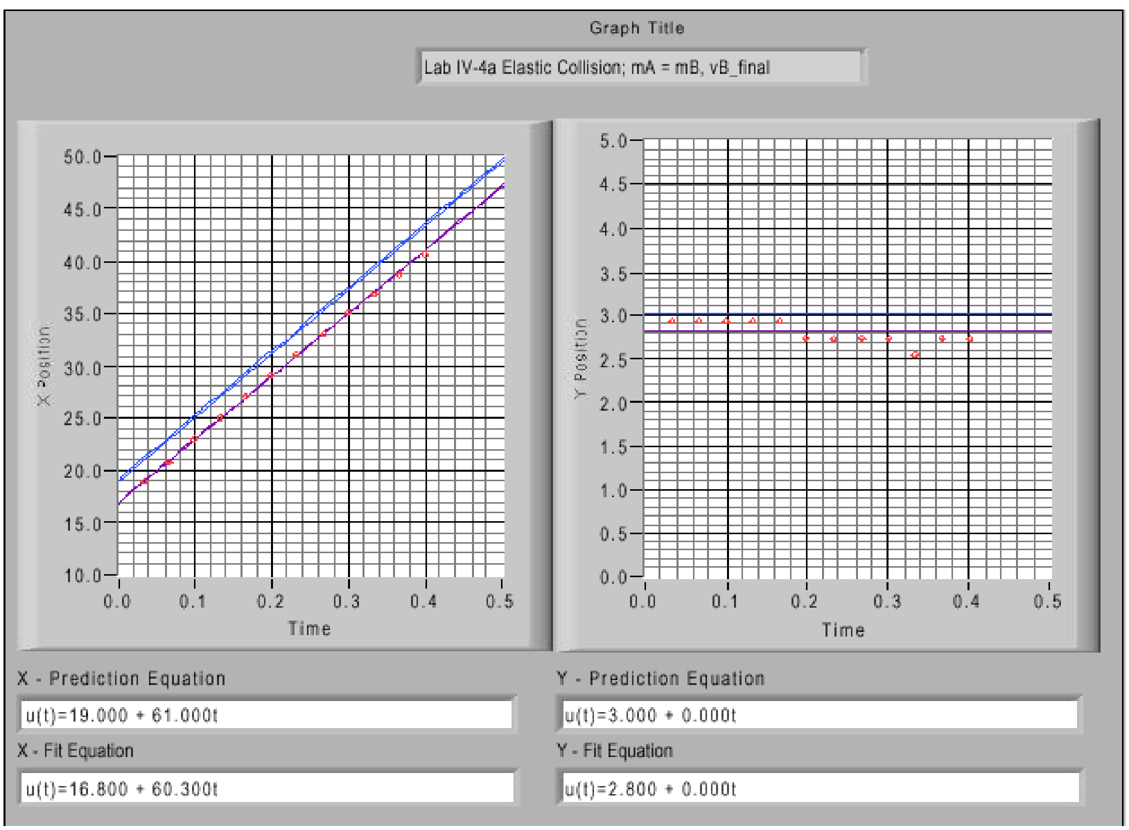
Mass cart 1: m_1 = 252.80g; Mass cart 2: m_2 = 753.92g

INITIAL VELOCITY OF CART 1: V = 51.70 CM/S
Energy efficiency: Eff = 0.98

PREDICTED FINAL VELOCITY OF CART 1: V_1' = -25.22 CM/S
MEASURED FINAL VELOCITY OF CART 1: V_1' = -25.50 CM/S
Predicted final velocity of cart 2: v_2' = 25.79 cm/s

Measured final velocity of cart 2: v_2' = 25.70 cm/s


Graph Title
Lab IV-4a Elastic Collision; mA = mB, vA_initial
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-30.000 + 65.000t
X - Fit Equation
u(t)=-30.100 + 61.200t
Y - Prediction Equation
u(t)=3.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t


Graph Title
Lab IV-4a Elastic Collision; mA = mB, vB_final
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=19.000 + 61.000t
X - Fit Equation
u(t)=16.800 + 60.300t
Y - Prediction Equation
u(t)=3.000 + 0.000t
Y - Fit Equation
u(t)=2.800 + 0.000t

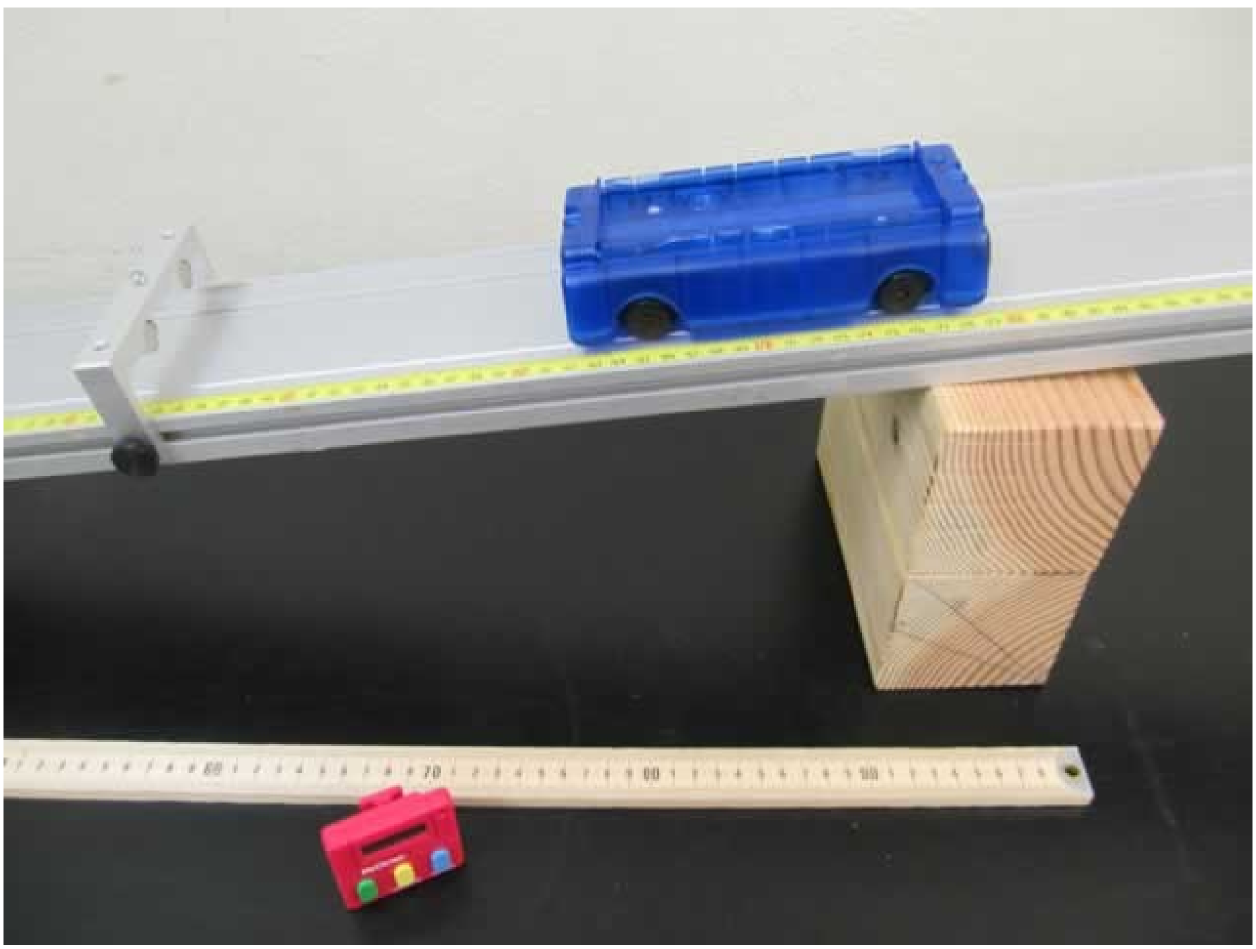
LAB 2, PROBLEM 3: ACCELERATION OF AN OBJECT DOWN AN INCLINE

PURPOSE

- To give students a chance to solve a (for them) real problem using energy, particularly gravitational potential energy.
- To relate the concepts of energy and potential energy to concepts with which they are more familiar.
- To give an explanation of the equation $a = g\sin\theta$ for the acceleration of an object down an inclined plane from first principles, since Mazur's text simply states it as empirical.

EQUIPMENT

Track, cart, end stop, wooden blocks, meter stick, stopwatch



TEACHING TIPS

- At this point in the semester, students have not worked with the concepts of forces or work, so you cannot use either of these concepts in class. You can find the derivation using only kinematics and conservation of energy in the "Prediction and Warm-up Questions" section below.
- **Do not** lecture about forces or work!

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students' previous experience with energy may leave them confused about the usefulness of the principles of energy. Students tend not to differentiate well between energy, force, power, and speed. Many students believe that energy is only conserved if a system has no interactions with its environment. Some also believe that conservation of energy means that the final kinetic energy of an object or group of objects equals its initial kinetic energy. Students are especially confused about potential energy. The whole idea that you need to define the system with which you are dealing before you can identify energy terms is foreign to most students.

Depending on how well they understand the equations (and simply are paying attention), students may end up with an initial velocity term in only the energy conservation equation or only in the kinematic equation. If they have it in both places or in neither, everything will work out fine. Push them in the direction that makes the most sense to them.

Students will tend to use the height of the object in the energy conservation part of the problem and the length of the track in the kinematical part of the problem. You may have to point out that they can relate these lengths.

PREDICTION AND WARM-UP QUESTIONS

Start with the conservation of energy. Let θbe the angle of inclination, and let $x$be the length that the cart accelerates down the inclined plane. Let zero potential energy be at the bottom of the length x.

$$E_i = T_i + K_i = mgxsin\theta + \frac{1}{2}mv_i^2 = E_f = T_f = \frac{1}{2}mv_f^2$$

Rearrange this equation so that it looks like the kinematical equation$v_f^2 - v_i^2 = 2ax$.

$$mgxsin\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$2gxsin\theta = v_f^2 - v_i^2$$

Now use that kinematical equation to solve for the acceleration.

$$2ax = 2gx sin\theta \Rightarrow a = g sin\theta$$

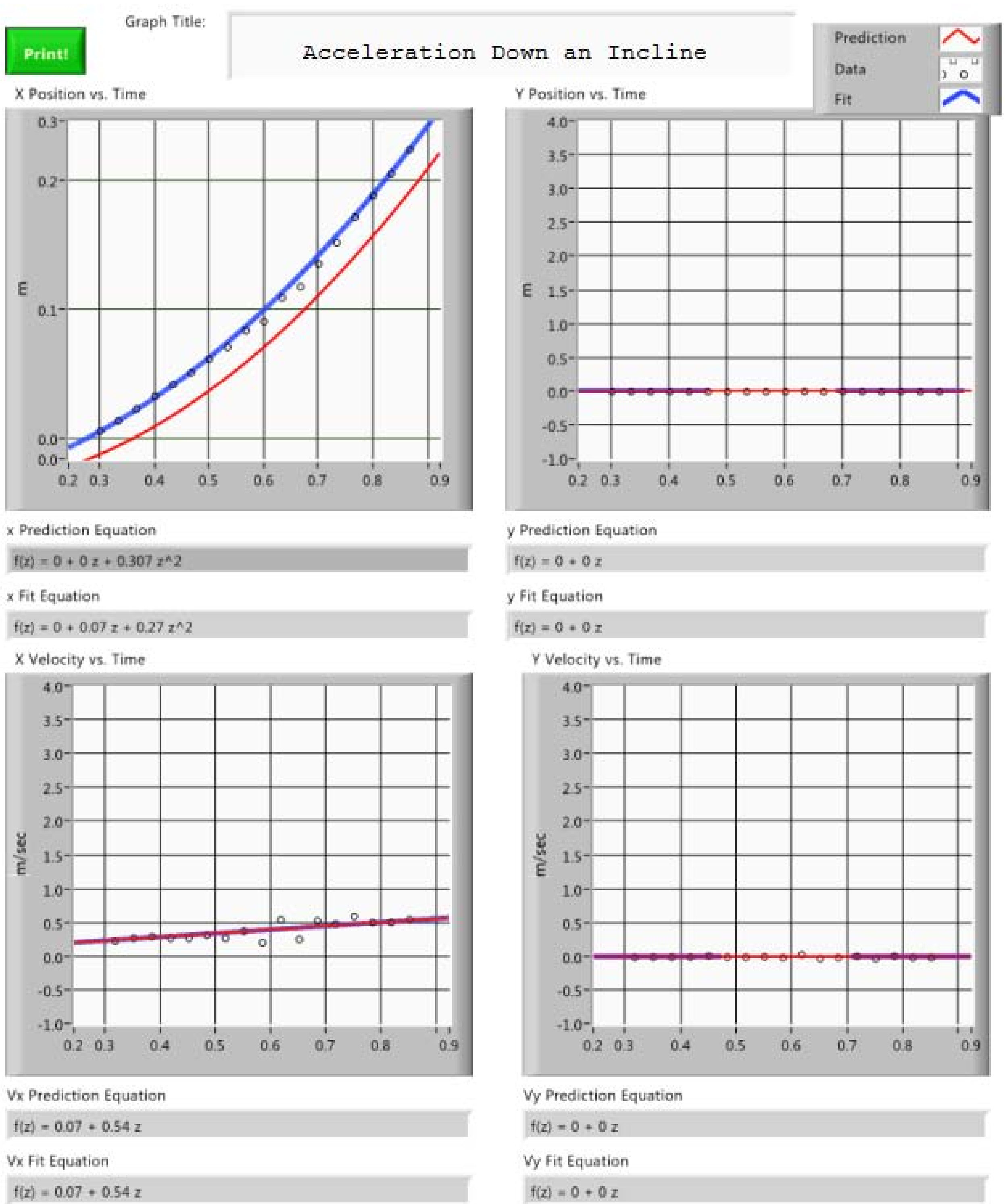
SAMPLE DATA

Initial height: 0.086m

Track length: 1.540m

Predicted acceleration: 0.55m/s

Measured acceleration: 0.54m/s


Print!
Graph Title:
Acceleration Down an Incline
Prediction
Data
Fit
X Position vs. Time
Y Position vs. Time
m
x Prediction Equation
f(z) = 0 + 0 z + 0.307 z^2
x Fit Equation
f(z) = 0 + 0.07 z + 0.27 z^2
y Prediction Equation
f(z) = 0 + 0 z
y Fit Equation
f(z) = 0 + 0 z
X Velocity vs. Time
Y Velocity vs. Time
m/sec
Vx Prediction Equation
f(z) = 0.07 + 0.54 z
Vx Fit Equation
f(z) = 0.07 + 0.54 z
Vy Prediction Equation
f(z) = 0 + 0 z
Vy Fit Equation
f(z) = 0 + 0 z

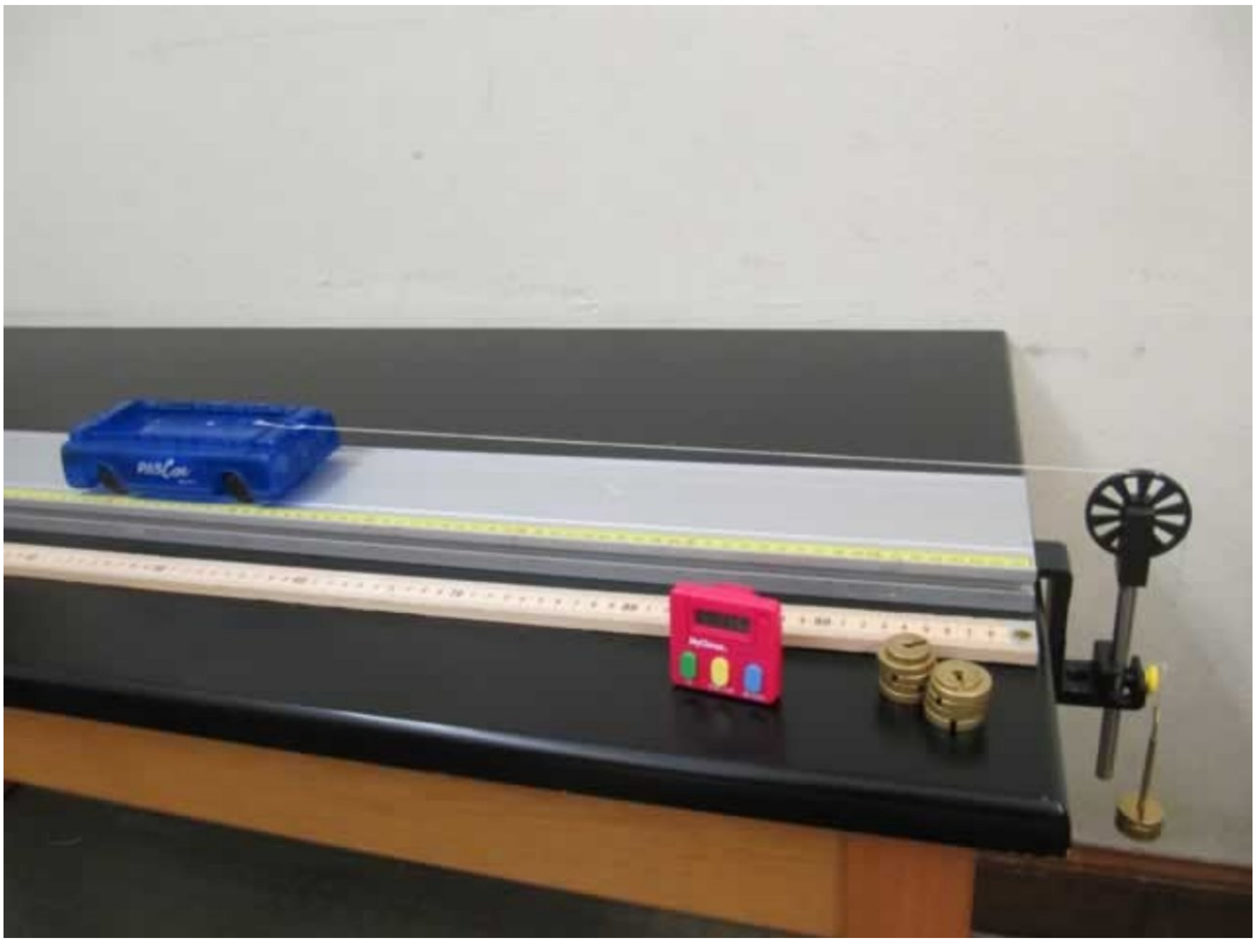
LAB 2, PROBLEM 4: VELOCITY AND ENERGY

PURPOSE

- To demonstrate the conservation of energy.
- To connect the concepts of potential energy and kinetic energy.

EQUIPMENT

Cart, track, string, pulley, end clamp, hanging mass set, meter stick, stopwatch



TEACHING TIPS

- Students don't understand the concept of forces yet, so you cannot use it in your class. They probably haven't gotten as far as work, either, so you probably shouldn't use it, either. If you do use it, do not relate it to force; that will come later, in lecture. Check with your instructor to see exactly how he wants you to teach this lab.

- Note that the students only need the final velocity, not the equation governing the motion as a function of time. If the length of string is long enough, the cart will continue to coast after the mass has already hit the ground, and the students can extract the final velocity as an approximately constant function during this phase. Even simpler measurements can be made, of course, but this is a good way to get reliable data.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students' previous experience with energy may leave them confused about the usefulness of the principles of energy. Students tend not to differentiate well between energy, force, power, and speed. Many students believe that energy is only conserved if a system has no interactions with its environment. Some also believe that conservation of energy means that the final kinetic energy of an object or group of objects equals its initial kinetic energy. Students are especially confused about potential energy. The whole idea that you need to define the system with which you are dealing before you can identify energy terms is foreign to most students.

Students may try to find the final velocity of the hanging mass using kinematics and the assumption $a = g$, ignoring the equation they just wrote down for the conservation of energy. Make sure they use the new concept of energy that is actually useful here instead of the familiar, comfortable concept of kinematics that is not.

PREDICTION AND WARM-UP QUESTIONS

$$v = \sqrt{2gh\frac{m}{m+M}}$$

SAMPLE DATA

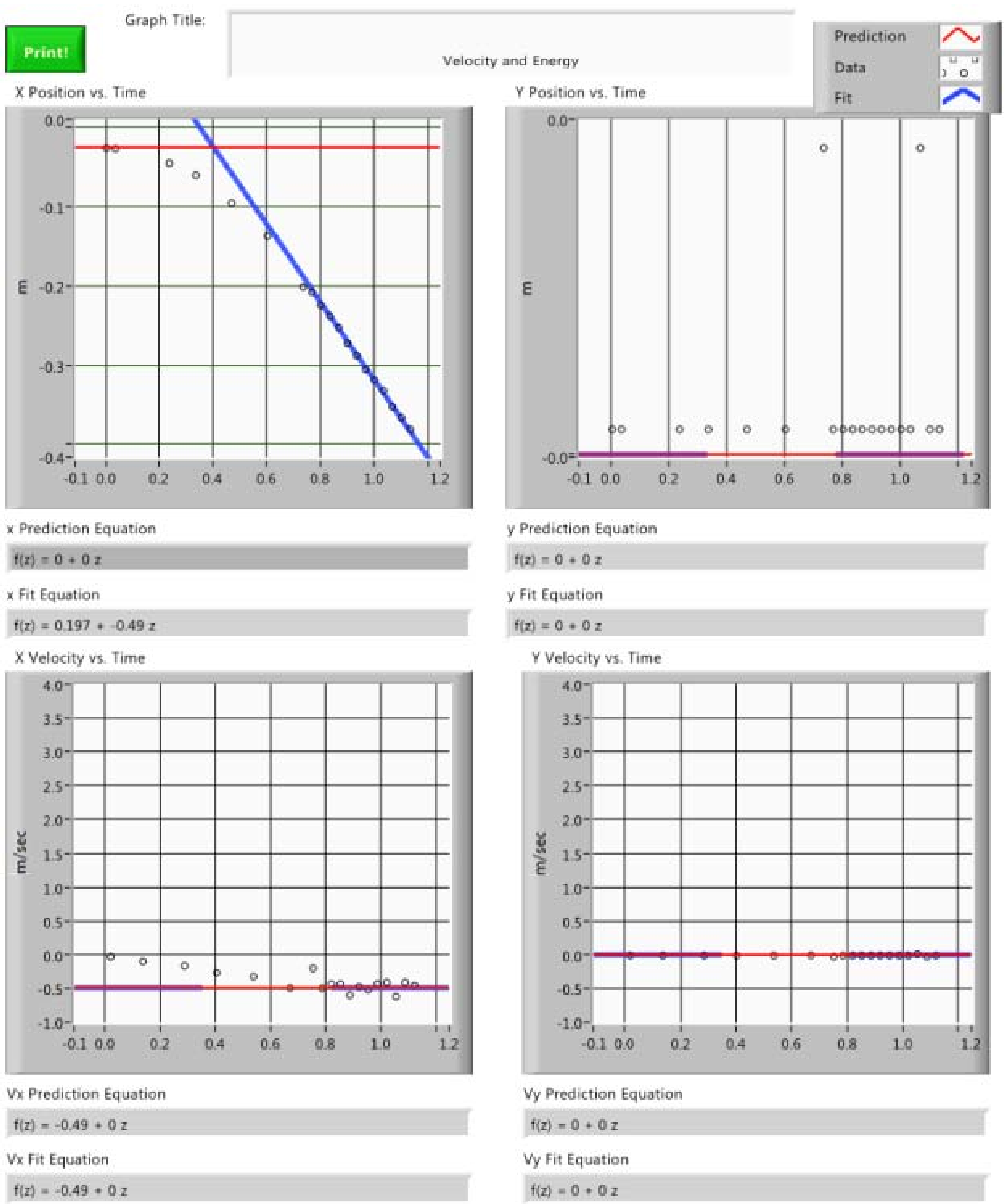
Cart mass: 255.4g

Additional cart masses: 251.8g, 250.0g

Hanging mass: 50.0g

Predicted final velocity: 0.493m/s

Measured final velocity:0.49m/s


Print!
Graph Title:
Velocity and Energy
Prediction
Data
Fit
X Position vs. Time
Y Position vs. Time
m
x Prediction Equation
f(z) = 0 + 0 z
y Prediction Equation
f(z) = 0 + 0 z
x Fit Equation
f(z) = 0.197 + -0.49 z
y Fit Equation
f(z) = 0 + 0 z
X Velocity vs. Time
Y Velocity vs. Time
m/sec
Vx Prediction Equation
f(z) = -0.49 + 0 z
Vy Prediction Equation
f(z) = 0 + 0 z
Vx Fit Equation
f(z) = -0.49 + 0 z
Vy Fit Equation
f(z) = 0 + 0 z

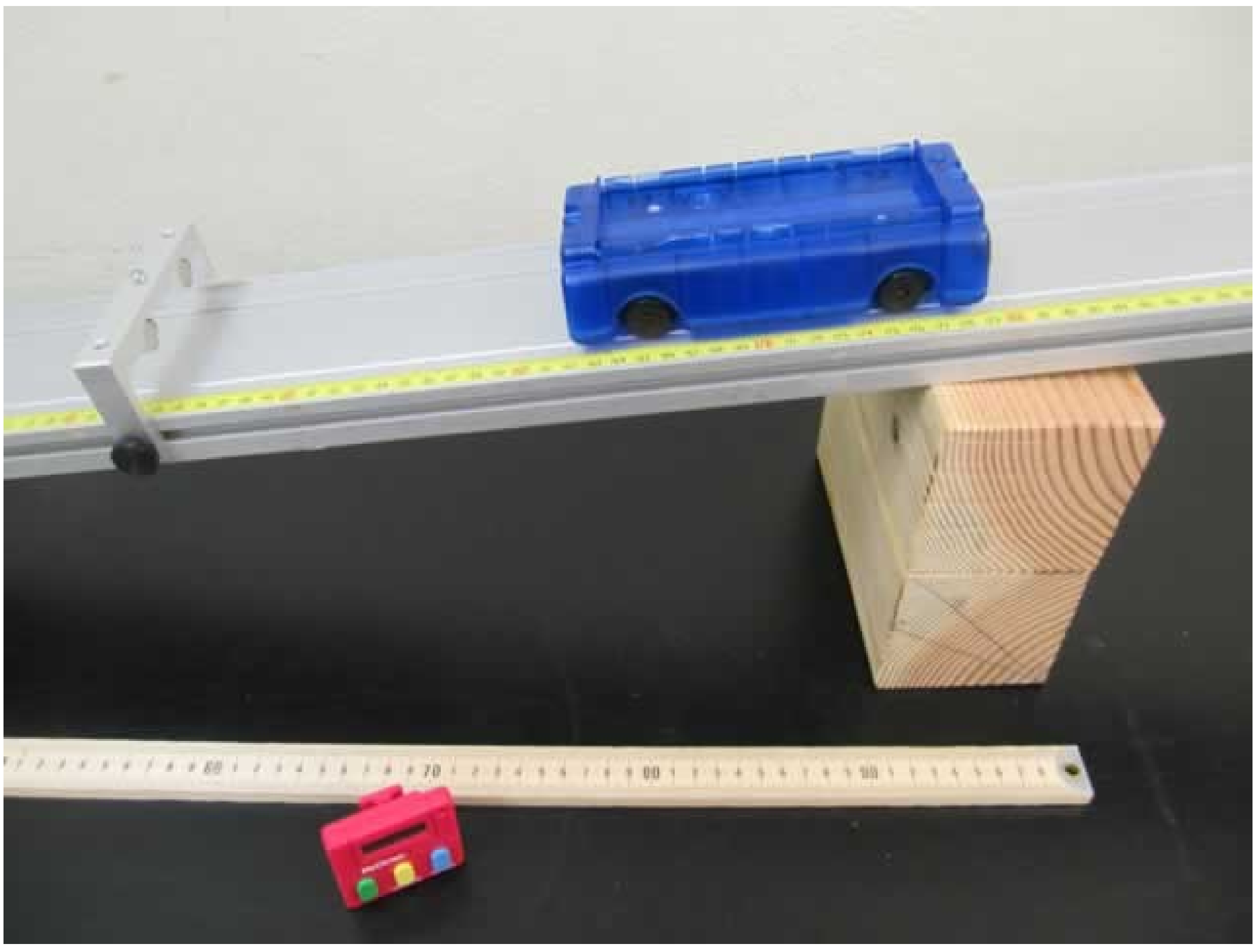
LAB 2, PROBLEMS 5 AND 6: KINETIC ENERGY AND EFFICIENCY

PURPOSE

- To introduce the students to the concepts of kinetic energy and work and how they are related through the conservation of energy.

EQUIPMENT

Track, cart, end stop, wooden blocks, meter stick, stopwatch



TEACHING TIPS

- This problem is a simple application of energy conservation that only requires the students to understand the concepts of kinetic energy and work.
- **Do not lecture on potential energy**; the lecture will probably not talk about potential energy until after the first week of this lab. **You do not need the concept of potential**

energy for this lab. Having the students figure out the problem in terms of work gives them good practice using this difficult concept.

- Remember to warn your students to avoid having their carts jump off the track.
- Warn your students to avoid the cart contacting the end stop during collisions. Have them try small velocities for problem #1 or small inclined angles for problem #2.
- Be sure to have the students share their results on the board. These results shouldn't vary too drastically from cart to cart. If the results do vary, it is most likely because of an analysis mistake. The students need an average value from everyone's results to apply to the equipment they use the following week.
- Suggest your students to correct the efficiency obtained in problem #2 by considering the dissipated energy from friction.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The common usage of the word "work" and the students' previous experience with energy may leave them confused about the usefulness of the principles of kinetic energy and work. Students tend not to differentiate well between energy, force, power, and speed. Many students believe that energy is only conserved if a system has no interactions with its environment. Some also believe that conservation of energy means that the final kinetic energy of an object or group of objects equals its initial kinetic energy. It is a common misconception that dissipated energy has been destroyed. Students are especially confused about work and potential energy. The whole idea that you need to define the system with which you are dealing before you can identify energy terms is foreign to most students. Students will tend to resist using energy when they first see it, since forces have been useful thus far.

PREDICTION AND WARM-UP QUESTIONS

PROBLEM 5

$$\text{Efficiency (level track)} = \left(\frac{v_f}{v_i}\right)^2,$$

where v_i is the velocity before the collision and v_f is the velocity after the collision.

PROBLEM 6

$$\text{Efficiency (inclined track)} = \frac{h_f}{h_i} = \frac{d_f}{d_i},$$

where h_i is the release height, h_f is the maximum height reached after the collision, d_i is the distance along the incline from the point of release to the bumper and d_f is the maximum distance along the incline from the bumper reached after the collision. The efficiency given in terms of the distance along the incline reinforces the concept of work while its relationship to height is a good introduction to the concept of potential energy.

Correction for efficiency of problem #2:

Given active length of magnets d_m, mass of the cart m, frictional force between cart and inclined track f and the inclined angle θ, we have

Kinetic energy just after collision (adding the dissipated energy from friction)

$K_f = mg * d_f \sin\theta + f * d_f$,

Kinetic energy just before collision

$K_i = mg * d_i * \sin\theta - f * d_i$.

$$\text{Corrected Efficiency}_{\text{inclined track}} = \frac{d_f}{d_i} * \frac{g\sin\theta + \frac{f}{m}}{g\sin\theta - \frac{f}{m}}.$$

From acceleration before collision a_{before} and acceleration after collision a_{after} we can figure out frictional force f and inclined angle θ.

$f = m * (a_{after} - a_{before}) / 2$

$g \sin\theta = (a_{after} + a_{before}) / 2$

SAMPLE DATA

PROBLEM 5

V_i=46 cm/s ; V_f=45 cm/s ;

Efficiency=0.96.

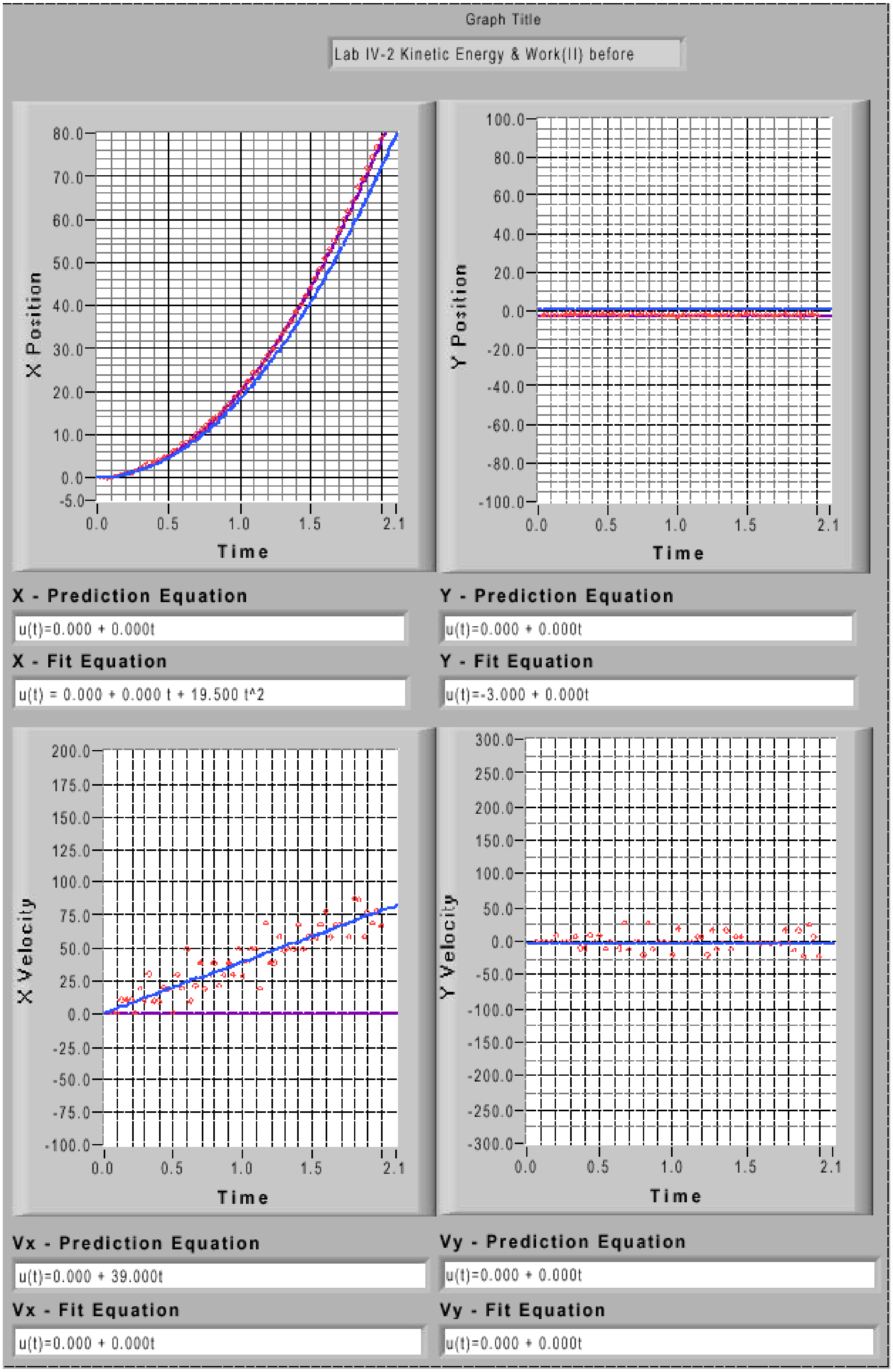
PROBLEM 6

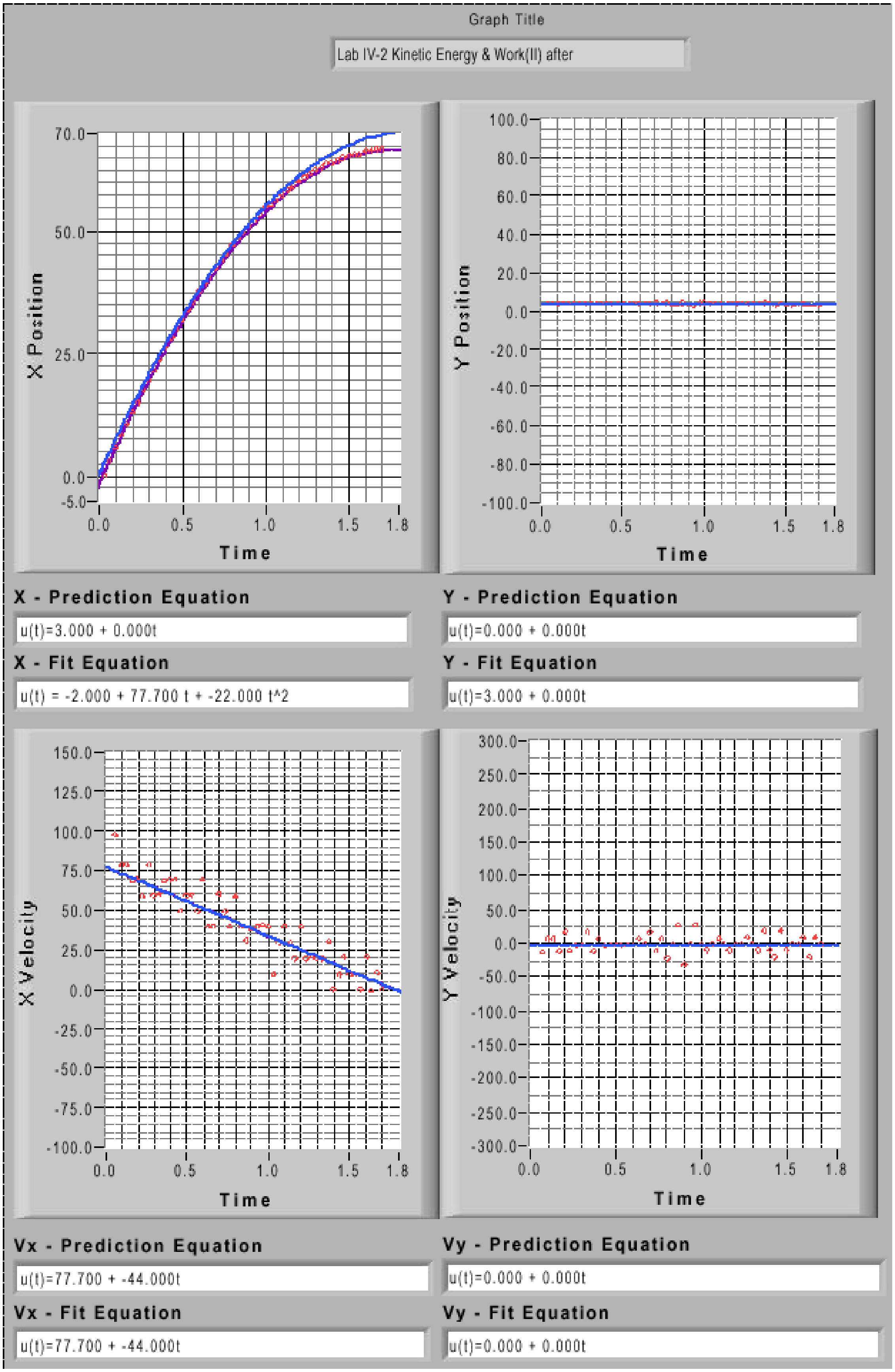
d_f=64 cm ; d_i=80 cm ; d_m=5cm ; a_{before}=39 cm/s^2 ; a_{after}=44 cm/s^2.

Efficiency(before correction)=0.80,

Efficiency(after correction)=0.91.

So we can consider the efficiency of bumper close to 1.

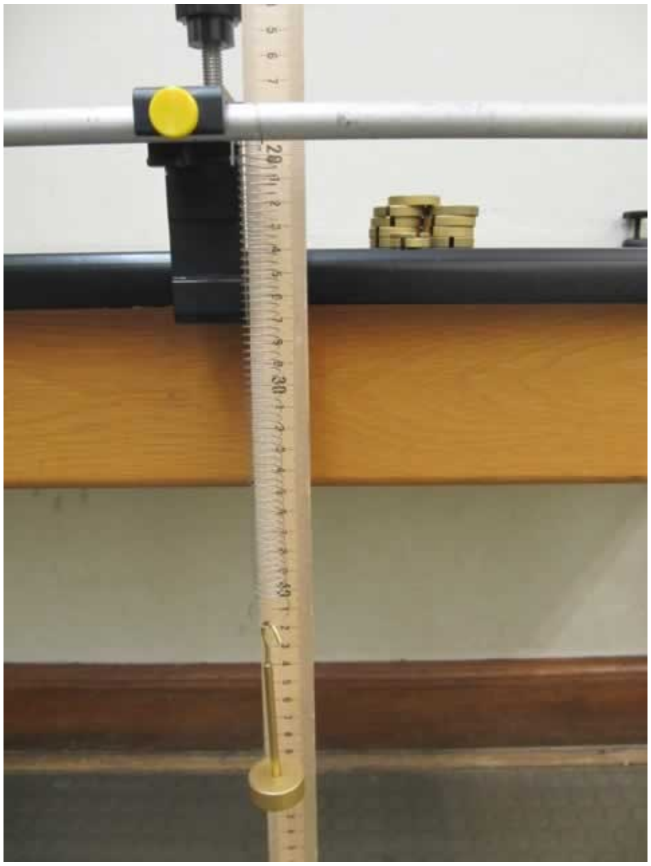

Graph Title
Lab IV-2 Kinetic Energy & Work(II) before
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 19.500 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 39.000t
Vx - Fit Equation
u(t)=0.000 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab IV-2 Kinetic Energy & Work(II) after
X Position
70.0
50.0
25.0
0.0
-5.0
0.0 0.5 1.0 1.5 1.8
Time
Y Position
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
0.0 0.5 1.0 1.5 1.8
Time
X - Prediction Equation
u(t)=3.000 + 0.000t
X - Fit Equation
u(t) = -2.000 + 77.700 t + -22.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
150.0
125.0
100.0
75.0
50.0
25.0
0.0
-25.0
-50.0
-75.0
-100.0
0.0 0.5 1.0 1.5 1.8
Time
Y Velocity
300.0
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
-250.0
-300.0
0.0 0.5 1.0 1.5 1.8
Time
Vx - Prediction Equation
u(t)=77.700 + -44.000t
Vx - Fit Equation
u(t)=77.700 + -44.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

LABORATORY 2, PROBLEM 7: MECHANICAL ENERGY OF A SPRING

PURPOSE

- To study the potential energy of a spring and investigate the conservation of energy in an oscillating system.



TEACHING TIPS

- Be sure not pass the elastic limit of springs. The hanging mass should be less than 200 g.
- During measuring, fix the top of the spring. Don't let it slide along ring stand. Try to keep spring-object system moving vertically without wobbling. Especially avoid spring-object system shake frontward and backward.
- For data collection in MotionLab, choose the reference point at the mass holder not at the spring since the spring will stretch during oscillation.
- Students should collect data over at least two complete periods. It is also important that the students take data at least every two frames. In their analysis, students will be asked to find the potential energy of a spring using gravitational potential energy and kinetic

energy. Unfortunately, when MotionLab calculates velocity, the position and velocity measurements are staggered in time. Therefore, it is important to take data points in small time increments to reduce the error in spring potential energy.

- Students will not need to fit the data taken in MotionLab. Make sure the students save the data points into a text file that can be imported into an Excel spreadsheet so that they can make the plot of spring potential energy vs. (displacement)^2 referred to in the prediction.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

This problem will be challenging for students since the methods for analyzing the data are different from what they have been doing so far. Students will likely struggle with using the position and velocity data to calculate how the gravitational potential and kinetic energy change over time. Many will be uncomfortable with putting equations into Excel and plotting the data.

PREDICTION AND WARM-UP QUESTIONS

From earlier labs, students will have learned how to find the spring constant by measuring the displacement from equilibrium when an object is suspended from the spring.

$$k = \frac{mg}{x_0} \tag{1}$$

x_0 is the displacement of the spring from its unstretched length when an object of mass m is suspended from the spring, g is the gravitational acceleration, and k is the spring constant

The students are then asked to hold the mass at the unstretched equilibrium position and let it go so that it begins oscillating. In the warm-up questions, students should write the equation for total energy just before letting go:

$$E_{tot} = U_{s,i} \tag{2}$$

$U_{s,i}$ is the initial spring potential energy. There is no gravitational potential energy since they are starting at the unstretched equilibrium (which was set to be the origin) and no kinetic energy since the system is starting from rest.

Then students are asked to calculate the total energy at any arbitrary time during the oscillation.

$$E_{tot} = U_s + mgx + \frac{1}{2}mv^2 = U_{s,i} \qquad (3)$$

x an arbitrary displacement from unstretched equilibrium, v is the velocity of the object at that displacement, and U_s is the spring potential energy at that displacement

To find the spring potential energy experimentally, students should rearrange the above equation to read

$$U_s = U_{s,i} - mgx - \frac{1}{2}mv^2 \qquad (4)$$

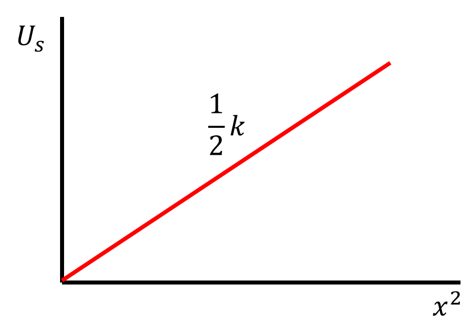
The main goal of the experiment is to verify the functional form of the spring potential energy,

$$U_s = \frac{1}{2}kx^2 \qquad (5)$$

Therefore, they should plot the spring potential energy calculated in equation (4) vs. x^2 and check that this results in a linear relationship with a slope of $\frac{1}{2}k$. As students calculate spring potential energy from equation (4), they may need to be reminded that $U_{s,i}$ is merely a constant due to conservation of energy and therefore leaving out this term will not affect the slope of their graph. Therefore, they don't need to know the form of spring potential energy in advance and ignore $U_{s,i}$.

PREDICTION

A plot of spring potential energy vs. displacement squared should result in a linear relationship with slope $\frac{1}{2}k$.



SAMPLE DATA

For the sample data, an initial amplitude different from the one suggested in the warm-up questions was used. The only thing this changes is the value of the total energy, which will not affect the slope of the plot of interest or the analysis procedure.

SPRING CONSTANT USING DISPLACEMENT

m = 70g = 0.07kg

x_0 = 20.7cm = 0.207m

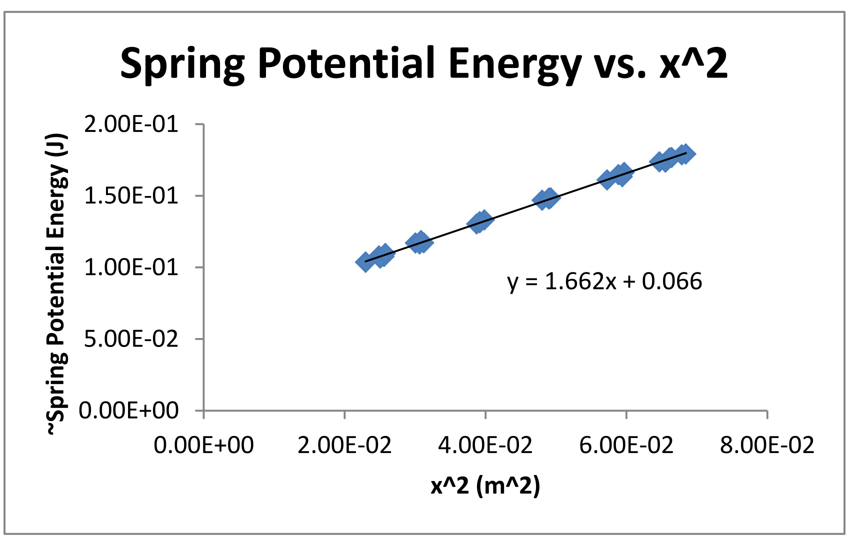
$$k = \frac{mg}{x_0} = \frac{(0.07kg) * \left(9.8\, {}^{m}/_{s^2}\right)}{0.207m} = 3.31\, {}^{kg}/_{s^2}$$

CALCULATING SPRING POTENTIAL ENERGY

$$U_s \propto -mgx - \frac{1}{2}mv^2$$

Table is included at the end. To deal with the staggered position and velocity points, the first position was matched with the first velocity given by MotionLab and the last position data point was eliminated. "PE spring" was calculated using just the terms that change with time (shown above).

Seeing that the relationship is linear, students can verify that the spring potential energy is proportional to x^2. Finally, students can check the value of the spring constant given by this plot with the one they calculated in part A).



SPRING CONSTANT USING THE SPRING POTENTIAL ENERGY VS. X^2 PLOT

slope $= \frac{1}{2}k$

$k = 2 * slope = 2 * 1.662 \approx 3.32 \ {kg}/{s^2}$

This result is surprising in how consistent it is with the spring constant found in part A), especially given the uncertainty introduced by the position and velocity data points being staggered in time. So even though this lab problem is slightly more challenging with the analysis than most labs, it will be meaningful for students to see the very clear linear relationship shown in their spring energy vs. x^2 plots and accuracy in deriving the spring constant using energy methods.

displacement (m)	velocity (m/s)	displacement^2 (m^2)	~PE spring (J)
-0.15159	-0.12564	0.02298	0.103438
-0.15997	-0.25128	0.02559	0.107526
-0.17672	-0.34341	0.03123	0.117102
-0.19961	-0.33504	0.03984	0.133004
-0.22195	-0.33504	0.04926	0.148329
-0.24428	-0.19265	0.05967	0.166277
-0.25713	-0.05026	0.06612	0.176303
-0.26048	0.06701	0.06785	0.178532
-0.25601	0.25128	0.06554	0.173413
-0.23926	0.30153	0.05725	0.160950
-0.21915	0.31828	0.04803	0.146791
-0.19794	0.36854	0.03918	0.131033
-0.17337	0.23453	0.03006	0.117007
-0.15773	0.09213	0.02488	0.107907
-0.15159	-0.10051	0.02298	0.103637
-0.15829	-0.25128	0.02506	0.106377
-0.17504	-0.32666	0.03064	0.116343
-0.19682	-0.36854	0.03874	0.130265
-0.22139	-0.31828	0.04901	0.148328
-0.24261	-0.22615	0.05886	0.164640
-0.25768	-0.05863	0.06640	0.176648
-0.26159	0.10889	0.06843	0.179036
-0.25433	0.15914	0.06468	0.173584
-0.24372	0.33504	0.05940	0.163263
-0.22139	0.35179	0.04901	0.147542
-0.19794	0.33504	0.03918	0.131858
-0.17560	0.22615	0.03084	0.118672

Print!

Graph Title:

Printed Wednesday, July 30, 2014, 2:31 PM

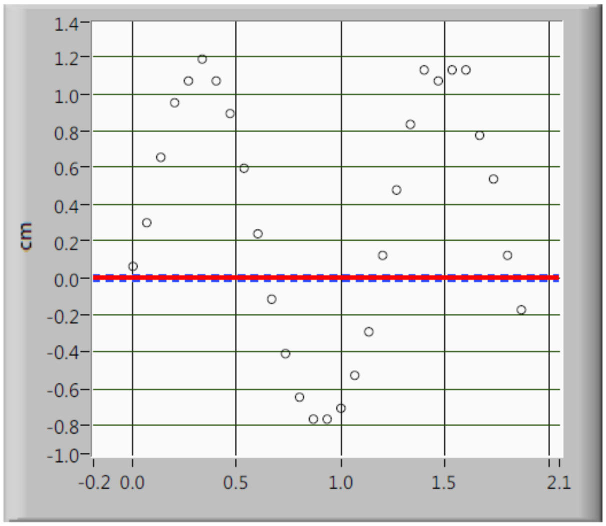
Spring Energy Lab

Prediction

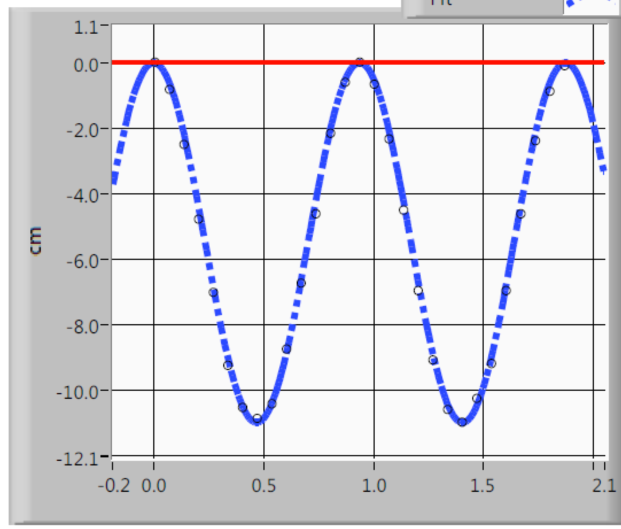
Data

Fit

X Position vs. Time



Y Position vs. Time



x Prediction Equation

f(z) = 0 + 0 z

x Fit Equation

f(z) = 0 + 0 sin (0 z + 0)

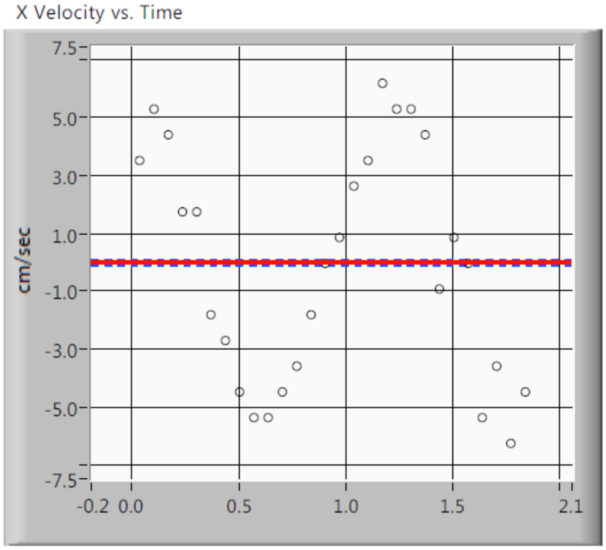
y Prediction Equation

f(z) = 0 + 0 z

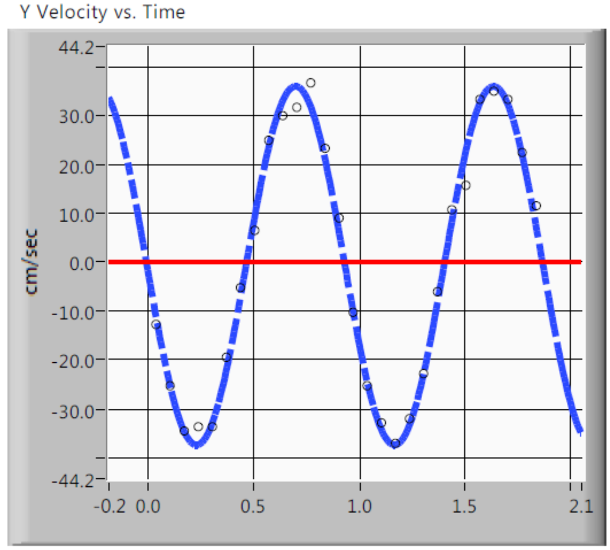
y Fit Equation

f(z) = -5.5 + 5.5 cos (6.7 z + 0.01)

X Velocity vs. Time



Y Velocity vs. Time



Vx Prediction Equation

f(z) = 0 + 0 z

Vx Fit Equation

f(z) = 0 + 0 z

Vy Prediction Equation

f(z) = 0 + 0 z

Vy Fit Equation

f(z) = -0.7 + -36.7 sin (6.7 z + 0.039)

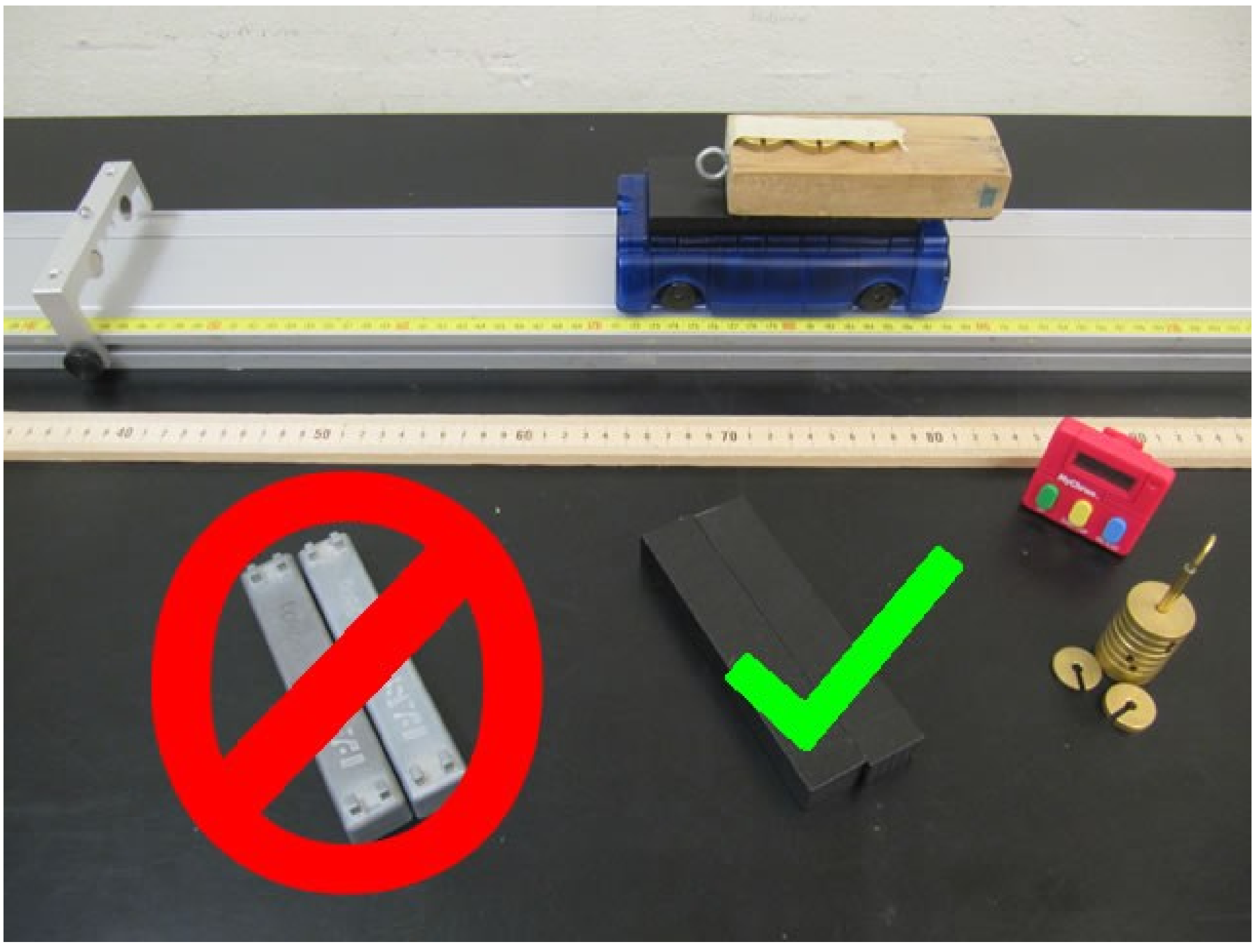
Lab 2, Problem 8: Energy and Friction

Purpose

To use the concept of conservation of energy when there is a change in kinetic energy of a system because energy is transferred from the system.

Equipment

Track, end stops, carts, meter stick, stopwatch, cart masses, friction block, mass set



Teaching Tips

1. This is a difficult problem for most students.
2. Keep in mind that this is a different type of problem than in most of the labs so far. The only way students can check if their results are reasonable is by comparing the coefficient of friction that they calculate with those in the table.
3. Keep the cart velocities reasonable to eliminate cart jumping.
4. The block to use is the small wooden one that is the same size as the carts.

5. You will need to have the masses in the carts for the block to slide.
6. The analysis for this problem uses the computer to get the initial velocity, and a ruler to get the distance the block slides.

DIFFICULTIES AND MAJOR ALTERNATIVE CONCEPTIONS

Students have a great deal of difficulty in breaking the situation up into different useful systems. They find it difficult to make the decision that the block of wood is the useful system in this case and the cart can be ignored. The concept of work is still very confusing for students.

Questions:

If a crate is riding on a truck, how does the distance it travels after the truck comes to a sudden stop depend on the speed of the truck?

PREDICTION AND WARM-UP QUESTIONS

$x = \frac{v^2}{2\mu_k g}$, where x is the distance the block slides, v is the initial velocity of the car, and μ_k is the coefficient of friction.

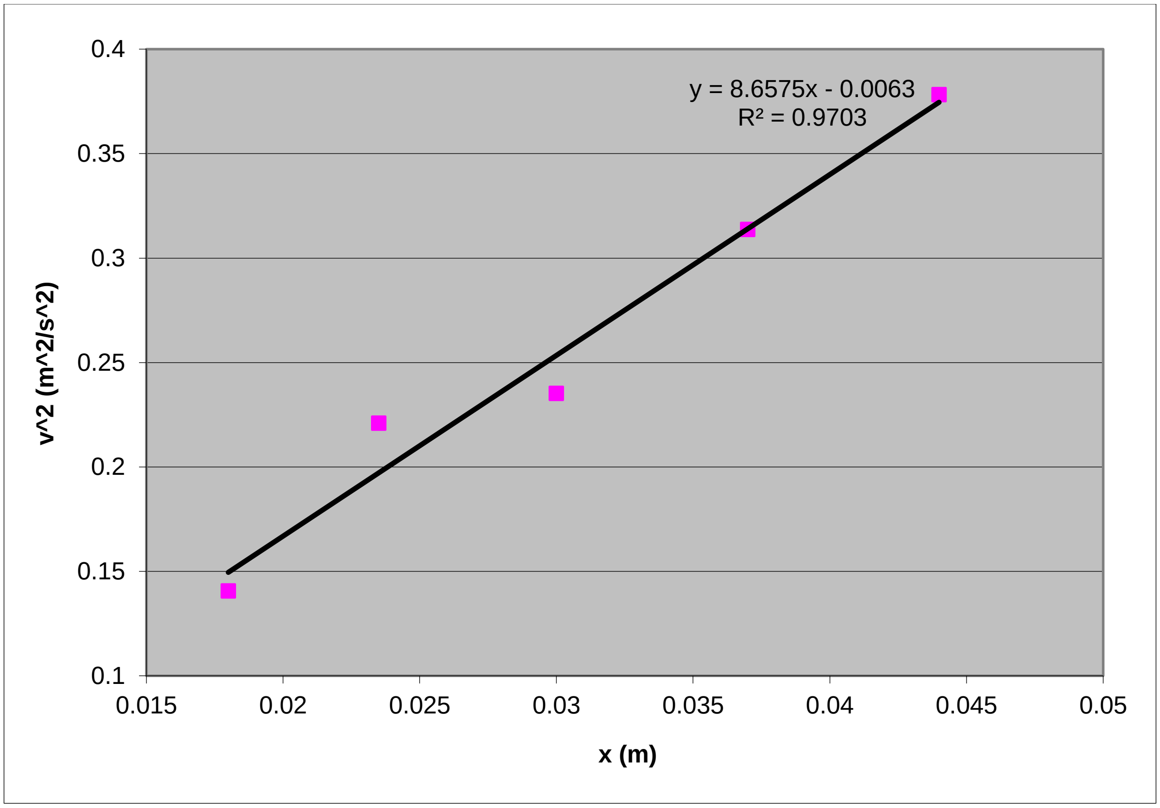
SAMPLE DATA

Some printouts for the measurements of velocities are included at the end of the sample data.

Data Table of distance X vs. Velocity

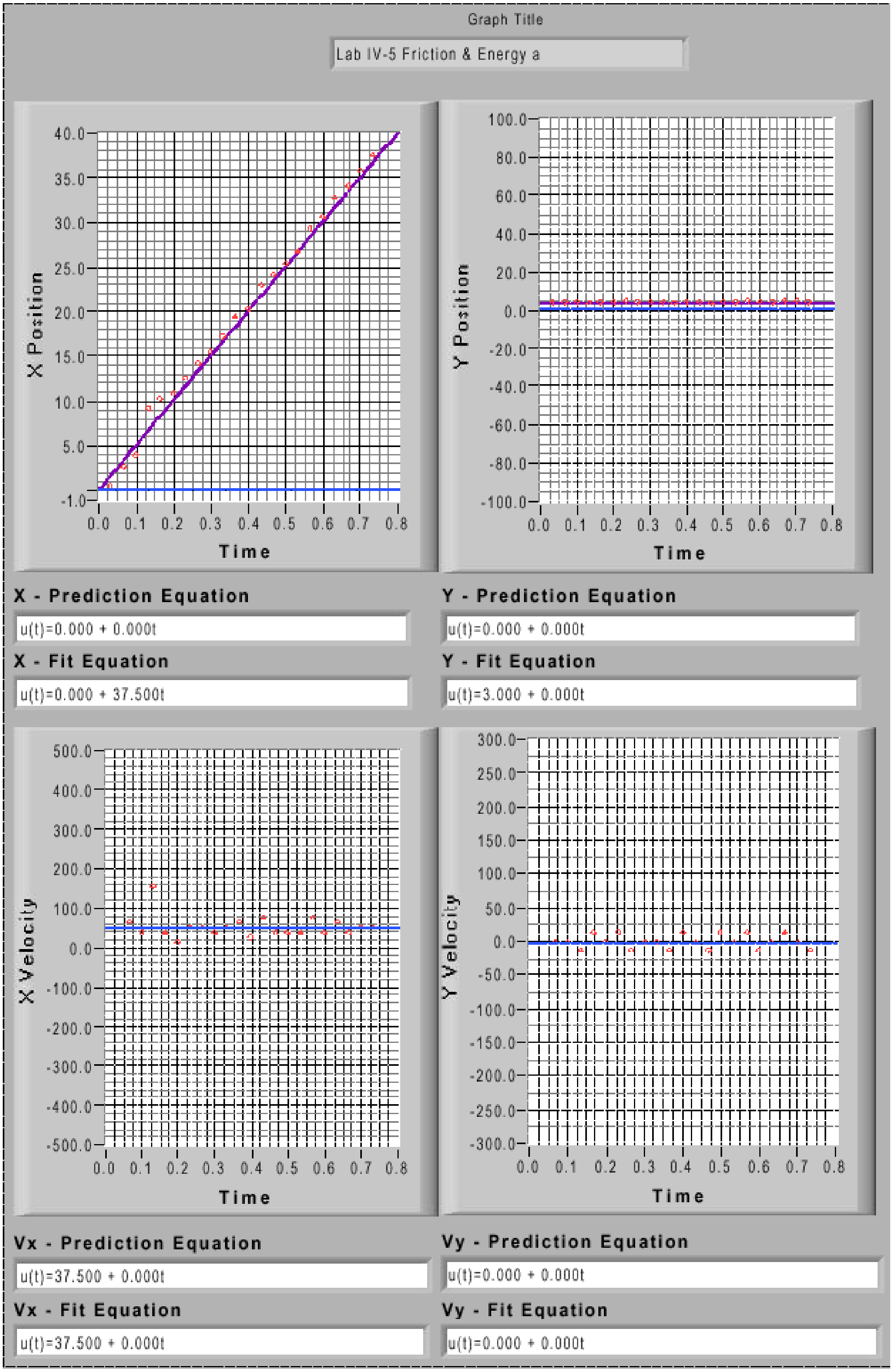
X (cm)	1.8	2.35	3.00	3.70	4.40
V (cm/s)	37.5	47.0	48.5	56.0	61.5

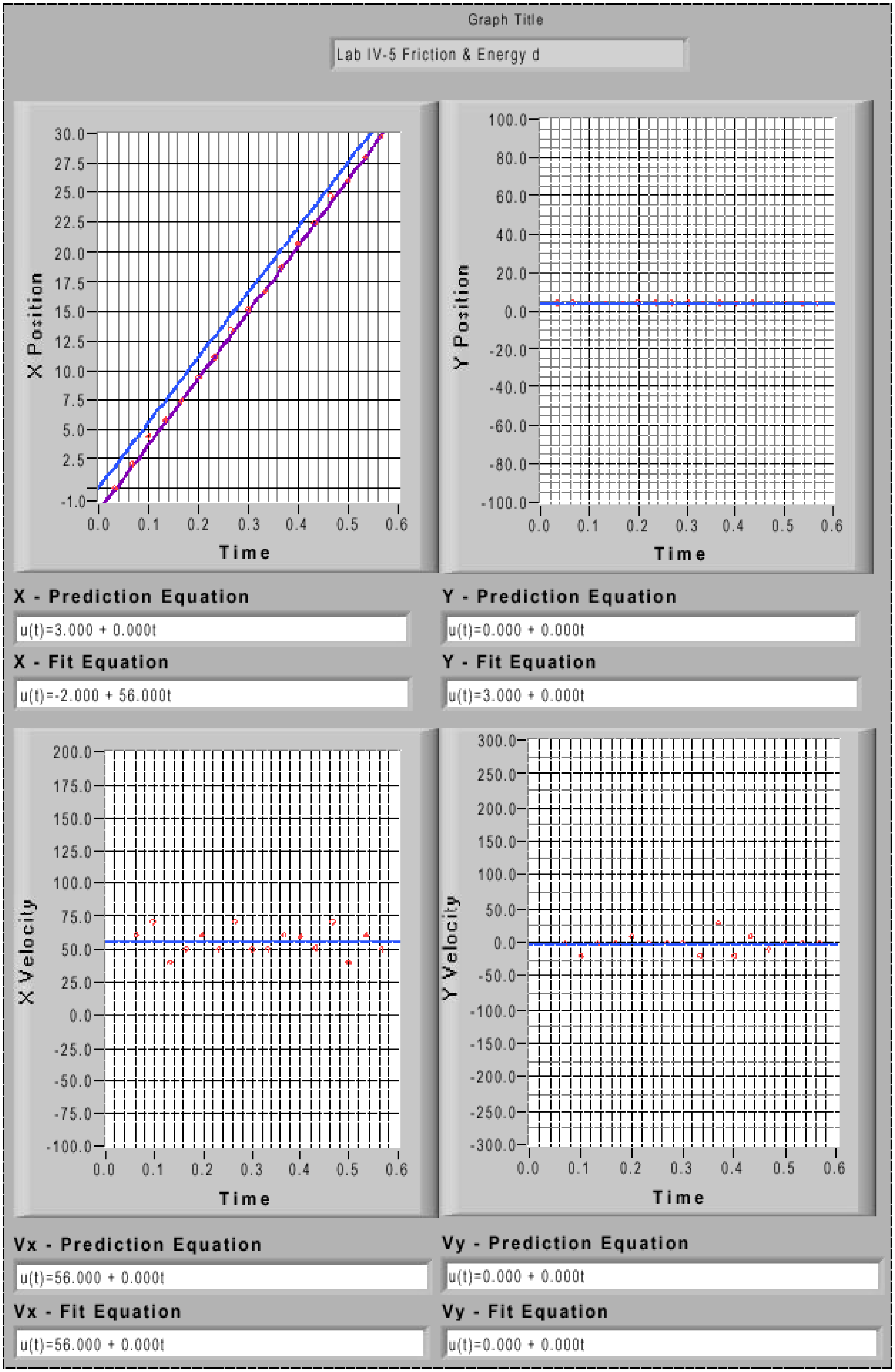
Fit line for X vs. V^2



From the slope of above picture we can calculate the coefficient of kinetic friction between wood/cloth block and cart masses

$$\mu_k = 0.44.$$


Graph Title
Lab IV-5 Friction & Energy a
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t)=0.000 + 37.500t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=37.500 + 0.000t
Vx - Fit Equation
u(t)=37.500 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab IV-5 Friction & Energy d
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=3.000 + 0.000t
X - Fit Equation
u(t)=-2.000 + 56.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=56.000 + 0.000t
Vx - Fit Equation
u(t)=56.000 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

TA Lab Evaluations

Physics 1301 Lab 2: Conservation of Momentum and Energy

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to **labhelp@physics.umn.edu**, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

Do you have additional comments regarding student learning and these labs?

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

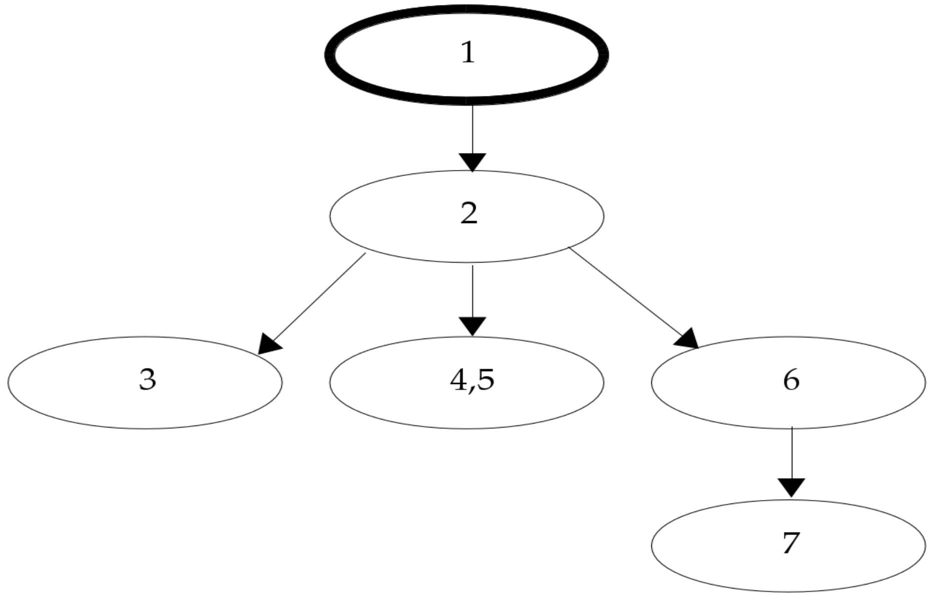
Lab Room

Was the room kept neat and clean by your class and other classes? (circle one) yes / no

Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

LABORATORY 3: FORCES



GENERAL TEACHING TIPS

- This is the first of the true sets of complete quantitative problem-solving labs. (Problem #4 of Lab 2 is really the first complete problem-solving lab.) Point out the difference to your students. Tell them of the new expectations of getting equations for their predictions as opposed to using an "educated guess" to determine the relevant physics quantity.
- The prediction for Problem #2 is challenging for the students. This is one prediction where at least half the class will not have a complete prediction. Resist the urge just to solve the problem for the whole class. Work with the individual groups so that they get it. A whole class discussion can be useful to point out the important factors that go into the solution. The students need to be able to do this type of problem themselves.
- Problems #4 and #5 are similar. You might consider dividing the class in half and letting each half do one problem. The halves can then combine into two large groups, compare their data, and each large group can do a 5-minute presentation.
- Students have plenty of alternative conceptions about forces. One force that is particularly confusing is the normal force. Be alert for students using the word "natural" to describe the normal force. This means that they do not associate the force with a direction. Explaining that in this case normal means perpendicular (make sure they know to what the force is perpendicular) may help.
- The key to the friction problems is making measurements as consistently as possible. A good discussion topic is to ask what different factors would affect consistency.
- Most of your students still have difficulty determining the components of vectors and understanding what these components mean. This lab repeats the use of vector components in the context of forces. Look for a recurrence of the mistakes you observed in kinematics.

- Refer your students to the **check your understanding** questions at the end of the lab. You might want to use some of these questions in your discussion

BY THE END OF THIS LAB, STUDENTS SHOULD BE ABLE TO

- Make and test quantitative predictions about the relationship of the sum of forces on objects to the motion of those objects for real systems.
- Determine which object is exerting a given force on the object in question.
- Use forces as vector quantities.
- Determine the characteristics of an "unknown" force.

THINGS TO CHECK OUT BEFORE TEACHING THIS LAB

- Check carts to see if the wheels will spin for an extended period.
- For Problem #1, it is nice, but not vital, that the cart avoids running over the string. Determine what you can suggest to students if they want to avoid the string.
- For Problem #2, make sure the pulleys that your students are using turn freely.
- Also for Problem #2, determine how to best set up the apparatus so that you can help your students use the largest range of masses.
- Also for Problems #4 and #5, the block slides differently if part of it is on the yellow ruler tape on the track. See how well you can avoid sliding the block along the yellow tape so that you are ready to give your students some advice if they need it.
- Try sliding the wooden block down the ramp at different angles (Problems #4 and #5) to determine where you will get consistent results. You don't need to take any data; careful qualitative observation should be enough.

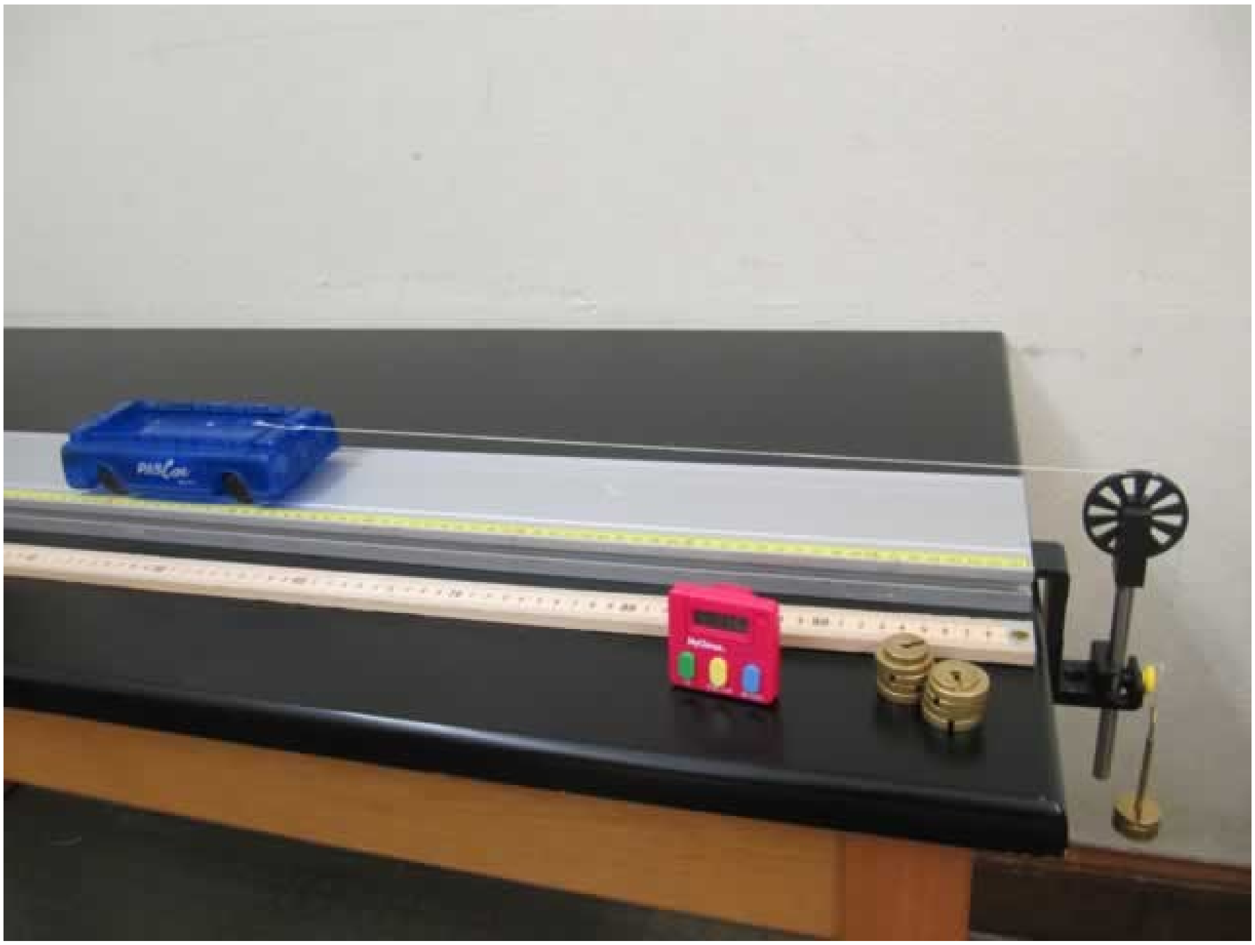
LAB 3, PROBLEM 1: FORCE AND MOTION

PURPOSE

- To show the students that the acceleration is proportional to the force exerted on an object and that the tension in the rope is **not equal** to the weight of the hanging mass.

EQUIPMENT

Track, cart, hanging mass set, end clamp, pulley, meter stick, stopwatch



TEACHING TIPS

- The students need enough string to hang over the pulley, but it should be long enough so that the mass hits the ground **before** the cart runs out of track.
- It is amazing how quickly students forget kinematics. This problem will reinforce the idea that physics builds upon itself.
- Many students may have difficulty with the necessity of drawing the two force diagrams required to solve this problem. Most will want to equate the force on the cart

with the weight hanging on the string. Avoid using the "clever" system of the weight + string + cart in your explanations. This system tends to confuse students and obscure the connection of forces with physical interactions.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Many students believe that the weight of the hanging mass is a force on the cart. Others know that the string is exerting a force on the cart but believe that the string tension is equal to the weight of the hanging mass.

PREDICTION AND WARM-UP QUESTIONS

$$v = \sqrt{\frac{2mgh}{m+M}}$$

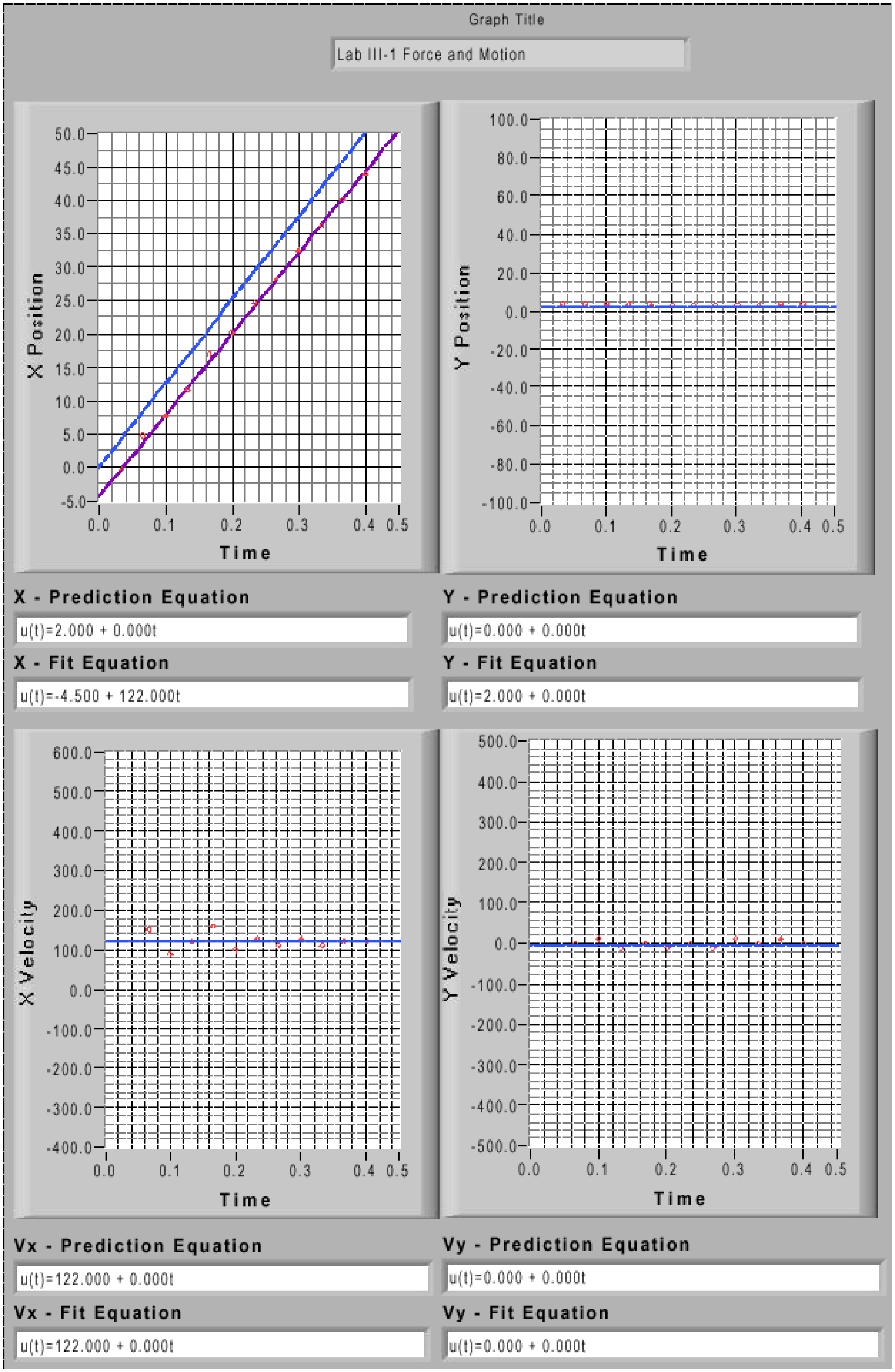
where m is the mass of object A, M is the mass of the cart and h is the height through which object A falls.

SAMPLE DATA

$m = 50.29$ (g), $M = 251.65$ (g), $h = 50$ (cm),

Predicted final velocity of the cart: $v = 1.28$ (m/s),

Measured final velocity of the cart: $v = 1.22$ (m/s).


Graph Title
Lab III-1 Force and Motion
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=2.000 + 0.000t
X - Fit Equation
u(t)=-4.500 + 122.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=2.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=122.000 + 0.000t
Vx - Fit Equation
u(t)=122.000 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

LAB 3, PROBLEM 2: FORCES IN EQUILIBRIUM

PURPOSE

- To have students use Newton's second law in a situation that requires the use of force components and the knowledge of the relationship of the direction of the forces to the geometry of the situation.

EQUIPMENT

Two clamps, two pulleys, three hanging mass sets, meter stick, string

TEACHING TIPS

- It is a good idea to tell your students, **before they come to lab**, that the algebra is messy. Students often think that they are doing something wrong if the algebra isn't simple. It is interesting to point out to your students that the equation is **not** simple even though the system is not particularly complicated. This is a good example of how quickly the mathematics can become complicated in the real world yet the problem remains solvable.

- Students will have trouble with the predictions. You should insist they do them before they arrive, but be prepared to dedicate class time to letting the students work on their predictions again after you compare group predictions in class. Lead a class discussion to highlight the difficulties that students are having and suggest solutions to those difficulties.
- Resist the urge to do the problem for the class. The students can do this problem if you have confidence in them. Let them try.
- Often students leave such quantities as θ in their equation. If another group does not point out that θ can be determined by measuring lengths, make sure you do so.
- This is a good opportunity to encourage your students to use extreme cases to check their results. Ask them to determine what happens when $M \to 0, \infty$. A discussion of taking limits is probably best done in the closing discussion after all measurements have been made.
- The students need a large enough mass range to show them that the curve is **not linear**. If the students aren't using a large enough range of masses, remind them to look at how the deflection depends on other quantities. They can bring the pulleys together or add masses to the outside weights to increase the range of the central mass before it hits the floor.
- For the sake of the analysis, assume no error on the masses. They can check this assumption with a balance.
- Encourage the students to explore both mass ranges $0 < M < m$ and $M > m$.
- An interesting test of the frictionless pulley assumption is to put unequal masses on each side (A and C) and find the maximum difference between A and C that causes the masses to move.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Many students do not connect the concept of a force with a physical interaction. They cannot determine the direction of a force from the physical connections of real objects. Some students still confuse the components of a force with the entire force.

PREDICTION AND WARM-UP QUESTIONS

$$h = \frac{LM}{2\sqrt{(2m)^2 - M^2}}$$

where M is the mass of object B, m is the mass of each of the objects A and C, L is the separation of the pulleys, and h is the vertical displacement of object B.

$$\sin\theta = \frac{M}{2m} \Rightarrow \tan\theta = \frac{M}{\sqrt{(2m)^2 - M^2}}.$$

SAMPLE DATA

$m_{\mathrm{A}} = 119.12\text{g}$; $m_{\mathrm{C}} = 119.21\text{g}$

Distance between two pulleys: $L = 40.0\text{cm}$

Mass of the suspended object M (g)	Predicted vertical displacement h (cm)	Measured vertical displacement h (cm)
49.48	4.2	4.2
68.85	6.0	6.0
77.92	6.9	6.9

In the calculation of the predicted vertical displacement the average value of m_{A} and $m_{\mathrm{C}}$was used for m.

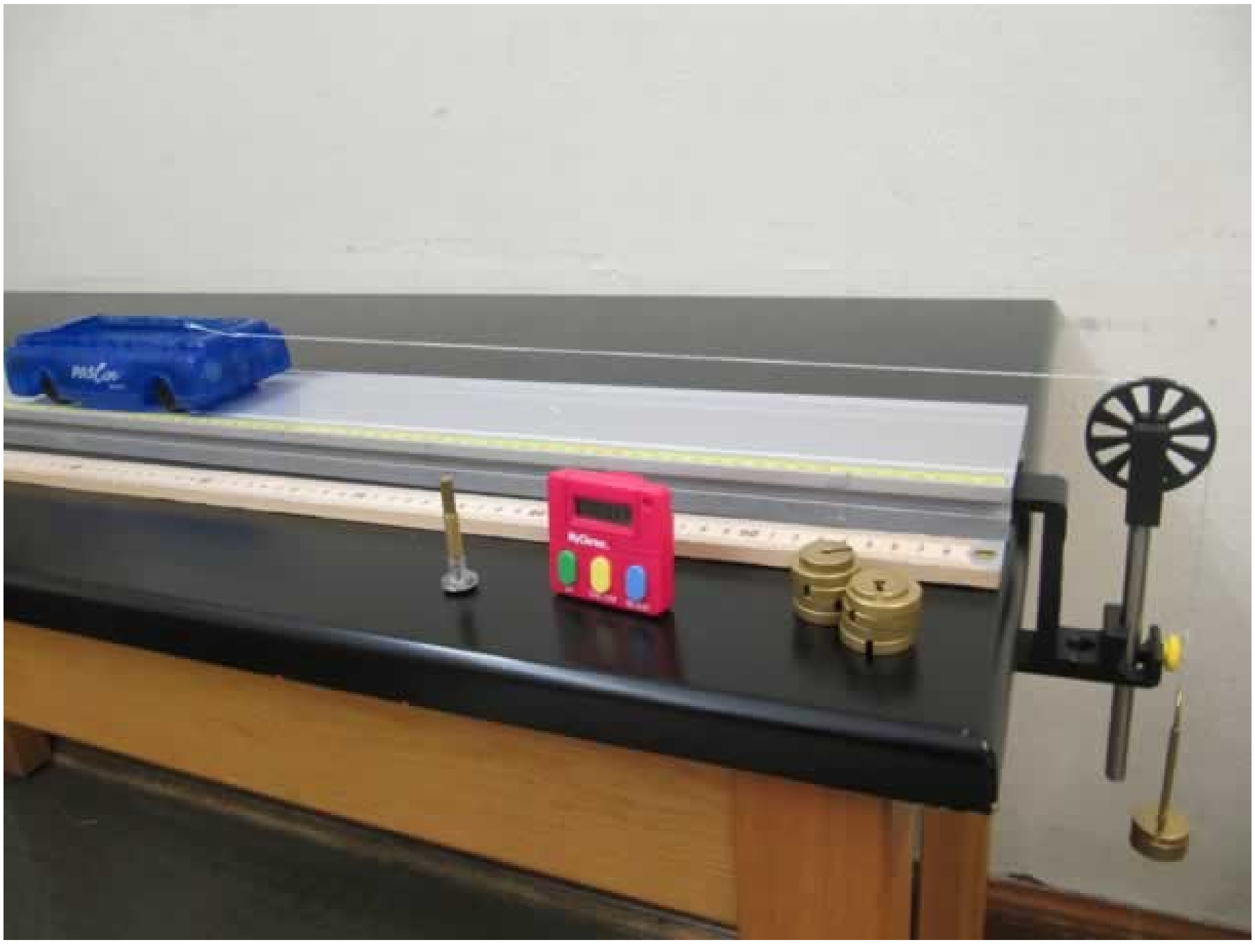
LAB 3, PROBLEM 3: FRICTIONAL FORCE

PURPOSE

- To show whether the frictional force changes value as a function of the acceleration of the object.

EQUIPMENT

Track, cart, string, pulley, clamp, hanging mass set, meter stick, stopwatch



TEACHING TIPS

- Be sure the students get the cart's motion both before <u>and</u> after the falling object hits the floor in the video.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The frictional force is difficult for the students. Students generally believe that the frictional force is always either a constant or equal to the weight of an object. They do not associate the frictional force with motion or a physical interaction with another object. Some of these students will have difficulties trying to relate the notion of initially over-coming static friction, which then leads to kinetic friction. They will also have difficulties deciding whether kinetic friction depends on the motion of the object in question.

PREDICTION AND WARM-UP QUESTIONS

$$f_1 = mg - (m + M)a_1,$$
$$f_2 = Ma_2,$$

where m is the mass of object A; M is the mass of the cart; f_1 and f_2 are the frictional forces on the cart before and after object A hits the ground, respectively; and a_1 and a_2 are the accelerations of the cart before and after object A hits the ground.

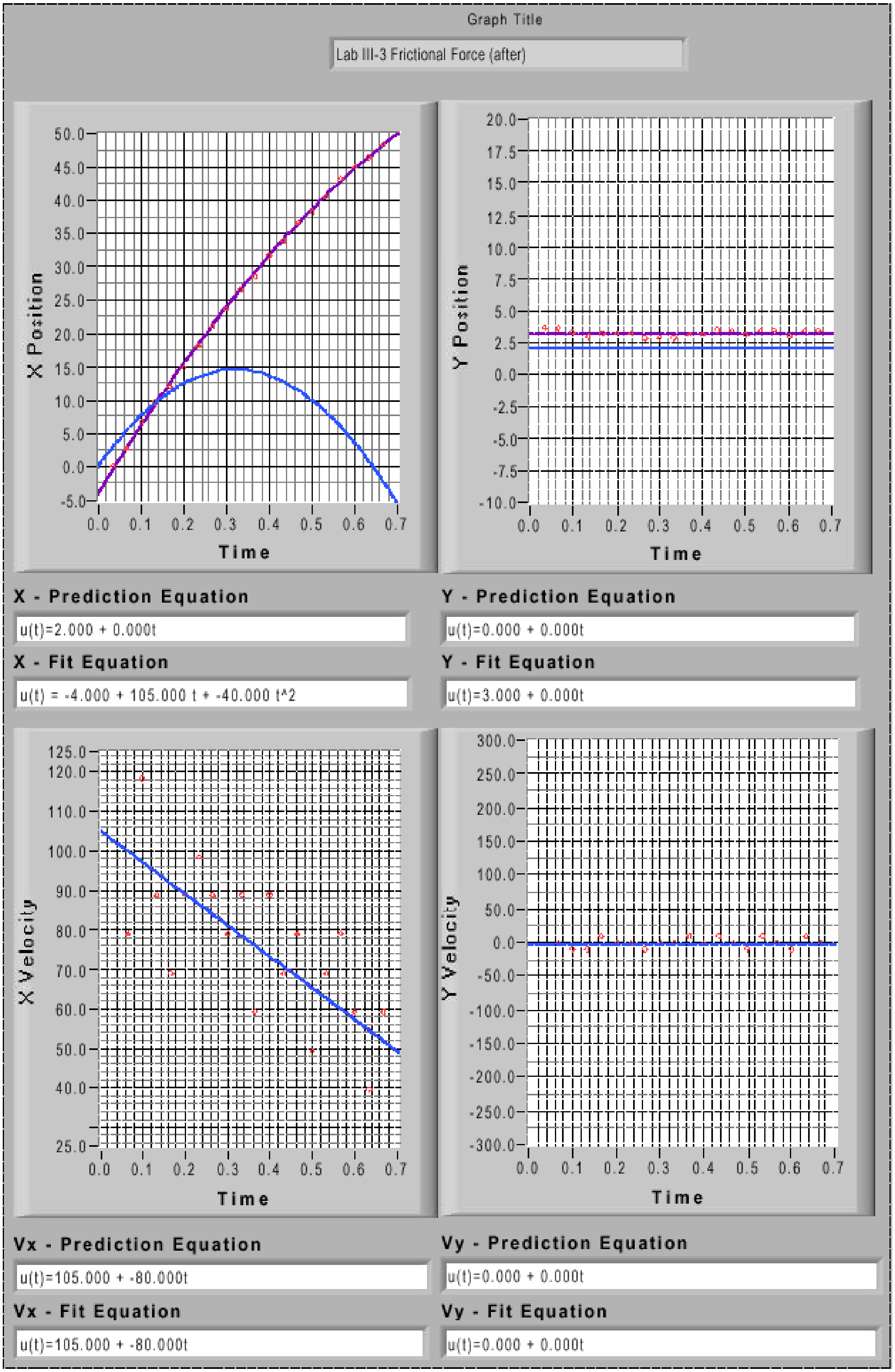
SAMPLE DATA

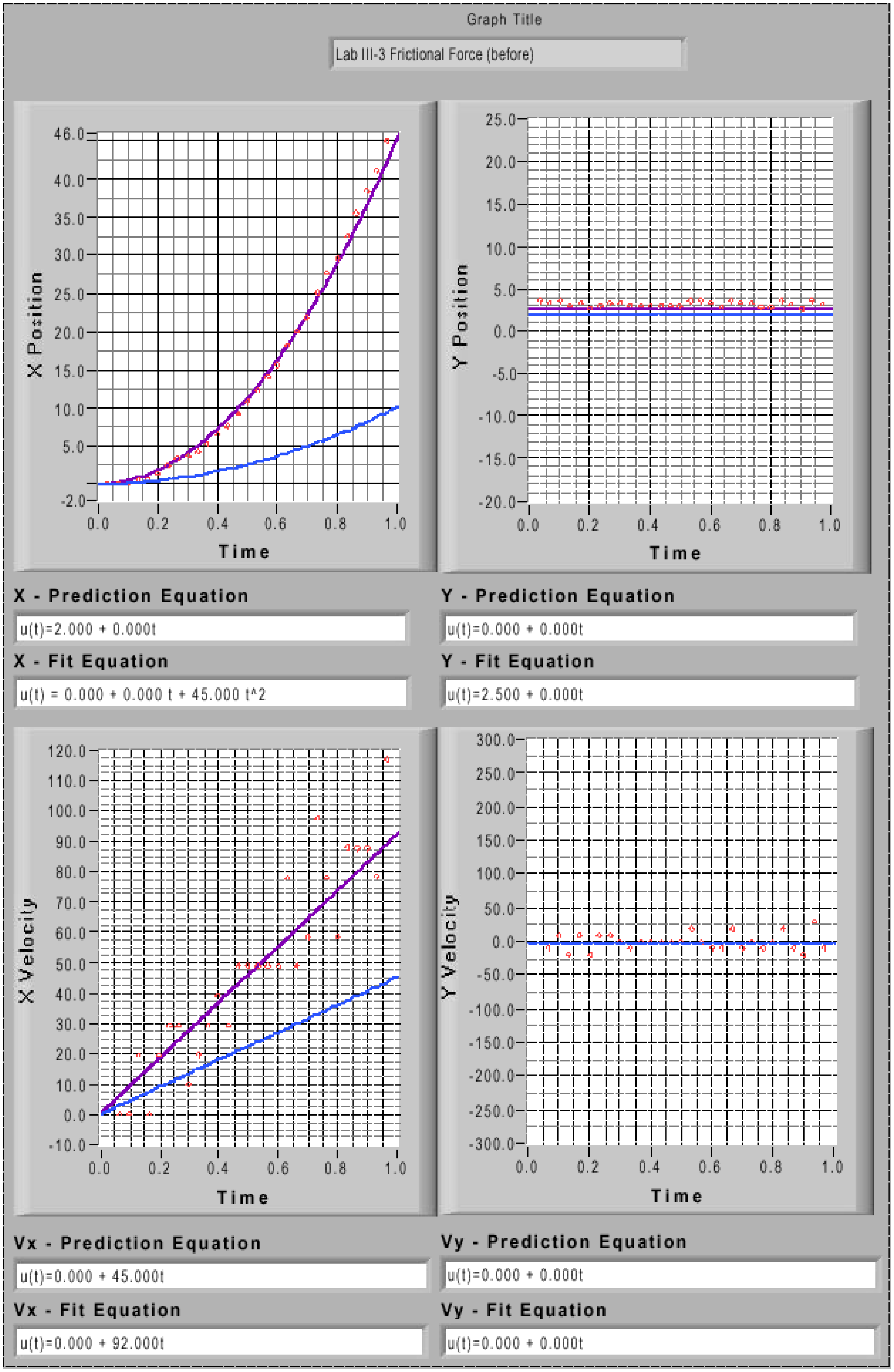
$m = 50.3\text{g}$, $M = 259.7\text{g}$,

Measured acceleration before object A hits ground: $a_1 = 90\ \text{cm/s}^2$; after: $a_2 = 80\ \text{cm/s}^2$,

Calculated frictional force before object hits ground: $f_1 = 0.214\ \text{N}$; after: $f_2 = 0.208\ \text{N}$.

The frictional force keeps same before and after the object A hits ground.

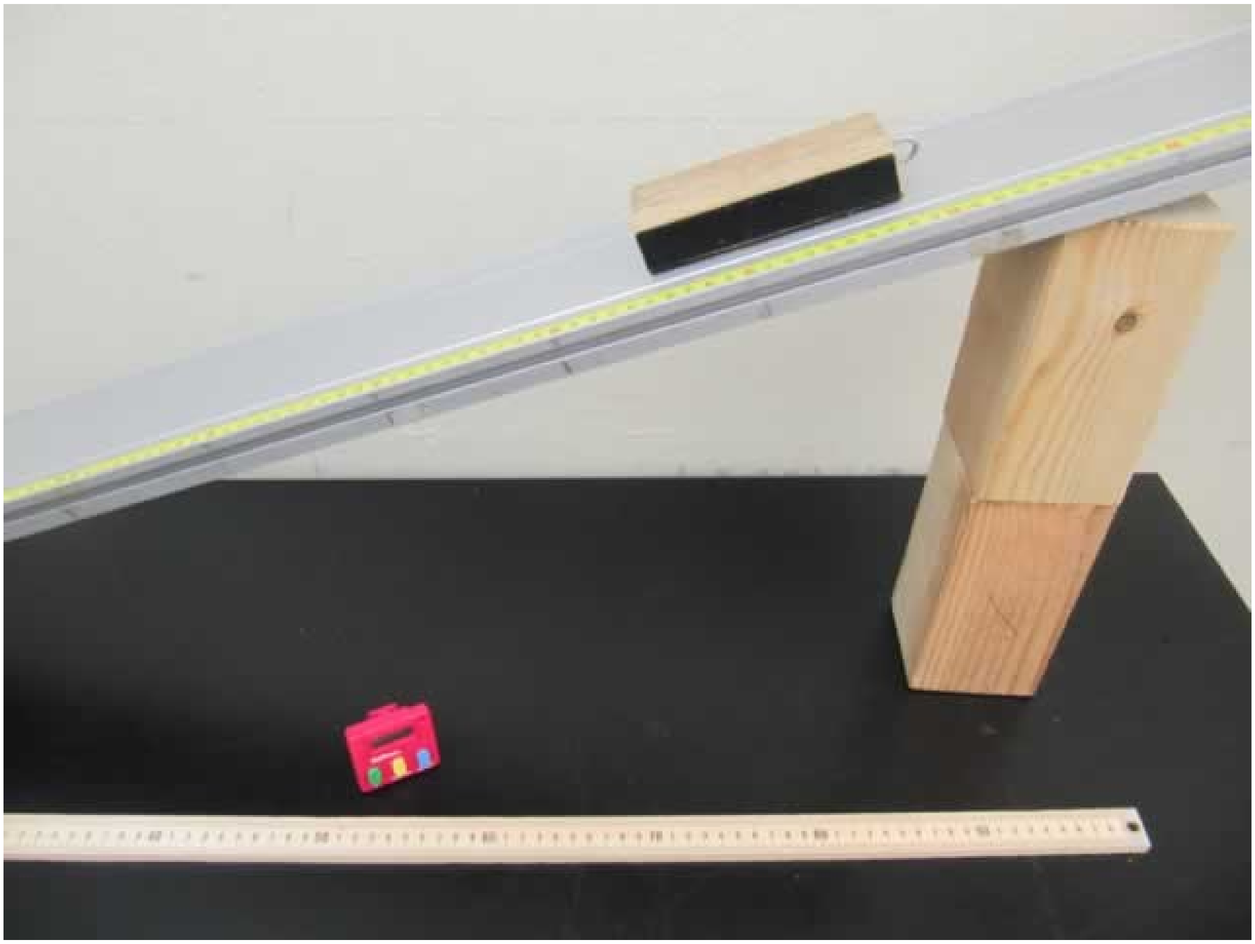

Graph Title
Lab III-3 Frictional Force (after)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=2.000 + 0.000t
X - Fit Equation
u(t) = -4.000 + 105.000 t + -40.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=105.000 + -80.000t
Vx - Fit Equation
u(t)=105.000 + -80.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab III-3 Frictional Force (before)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=2.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 45.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=2.500 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 45.000t
Vx - Fit Equation
u(t)=0.000 + 92.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

LAB 3, PROBLEMS 4 AND 5: NORMAL FORCE AND THE KINETIC FRICTIONAL FORCE

PURPOSE

To show the normal force does not have a fixed value. The normal force depends on the weight of the object (Problem 4) and on the angle of incline (Problem 5).



EQUIPMENT

Track, friction block, wooden blocks, block masses, meter stick, stopwatch

TEACHING TIP

- These labs address different parts of the same question. If there is enough time, it is useful to have each group do both problems. If there is not enough time, have half the class do one problem, the other half the other problem. The two halves should discuss their results separately. Then choose a representative from each side to present their findings to the entire class. Be prepared to lead this discussion.
- Be sure the block doesn't slide along the yellow ruler tape.

- It is important that the wooden block accelerate smoothly down the ramp, otherwise the friction force will not be constant. Increasing the angle of incline will help solve this problem.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The normal force is difficult for the students. Students generally believe that the normal force is always either a constant or equal to the weight of an object. They do not associate the normal force with a physical interaction with another object. These students believe that there is always a normal force, even if there is nothing touching the object. The angular dependence should help them understand the necessity of an interaction. The students often have difficulty relating the angle of the incline to the direction of the normal force.

PREDICTION AND WARM-UP QUESTIONS

$N = mg\cos\theta$,

$f_k = mg\sin\theta - ma$,

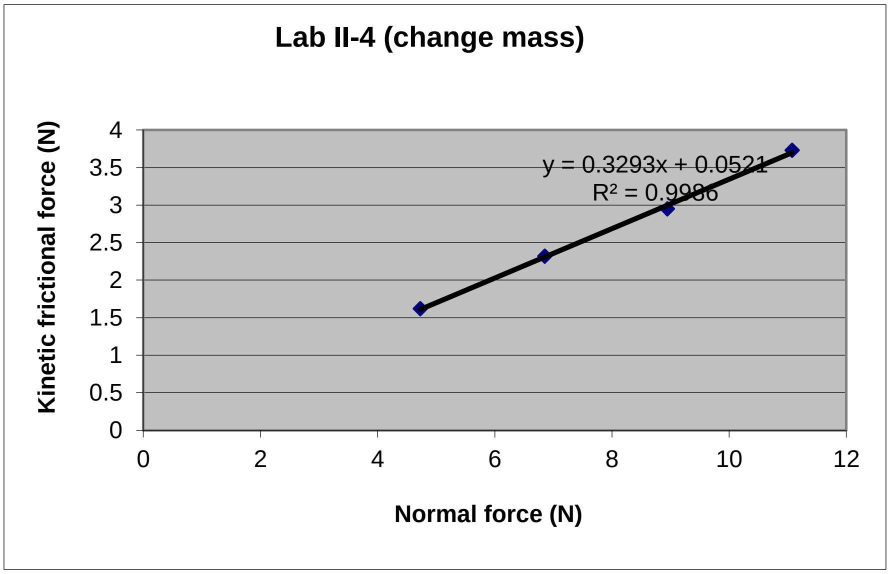
where θ is the angle of incline of the track to the horizontal, m is the mass of the wooden block and a is the acceleration of the wooden block moving down along the inclined track.

SAMPLE DATA

Problem 4:

Inclined angle: $\theta = 29.48^0$,

m (g)	554.5	804.5	1048.8	1298.8
a (cm/s^2)	190	194	201	195
Normal force N (N)	4.73	6.86	8.95	11.08
Frictional force. f_k (N)	1.62	2.32	2.95	3.73

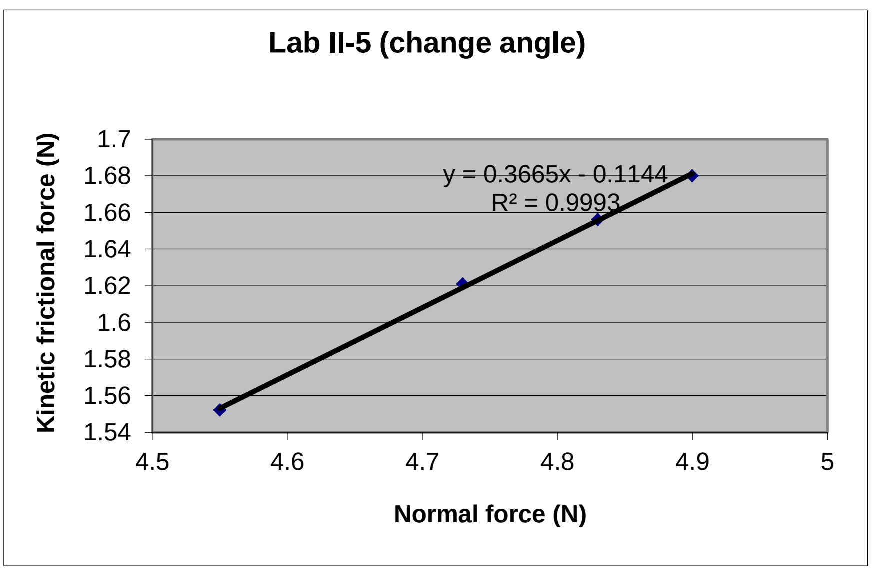


$\mu_k = 0.3293$

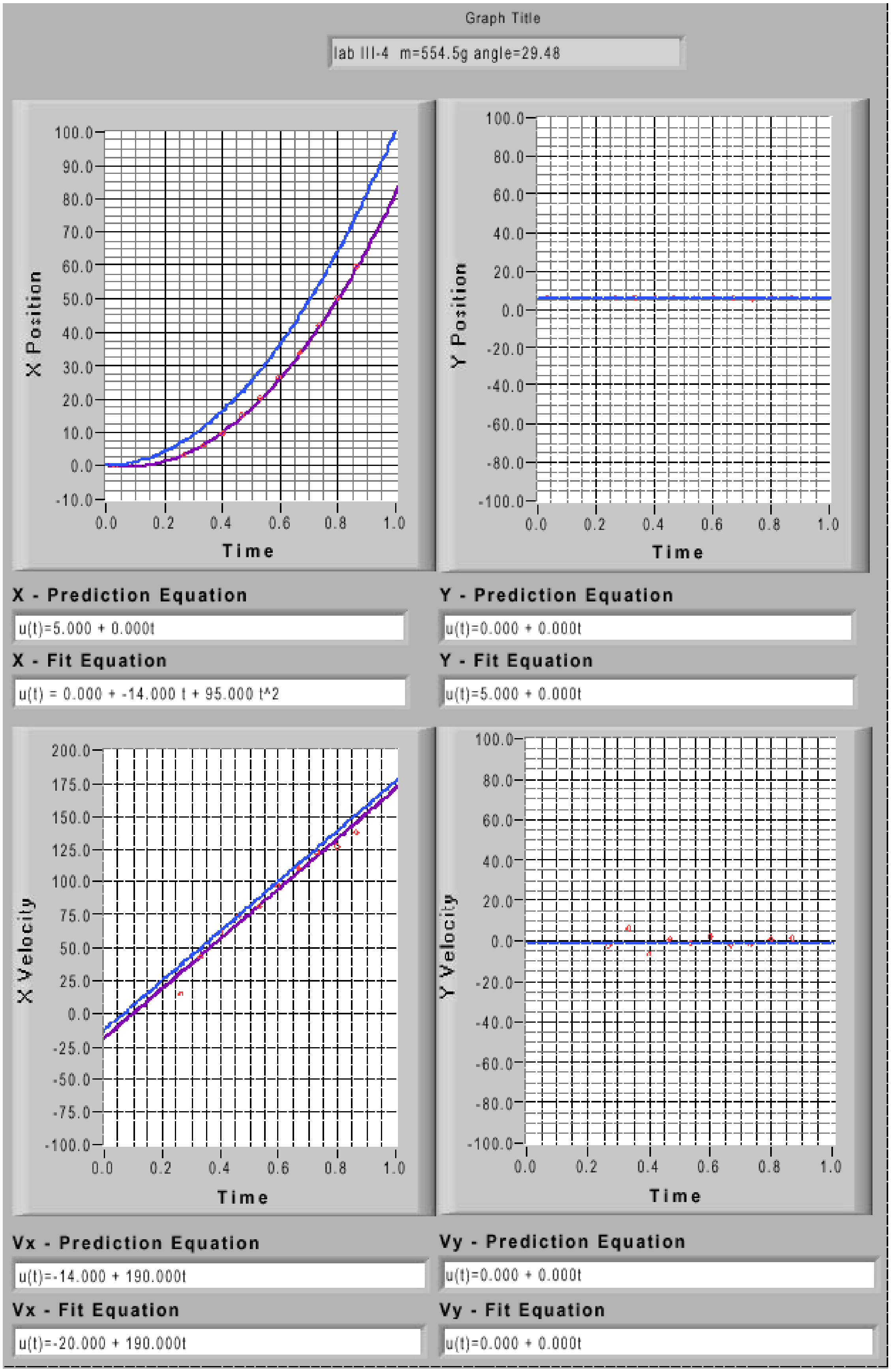
Problem 5:

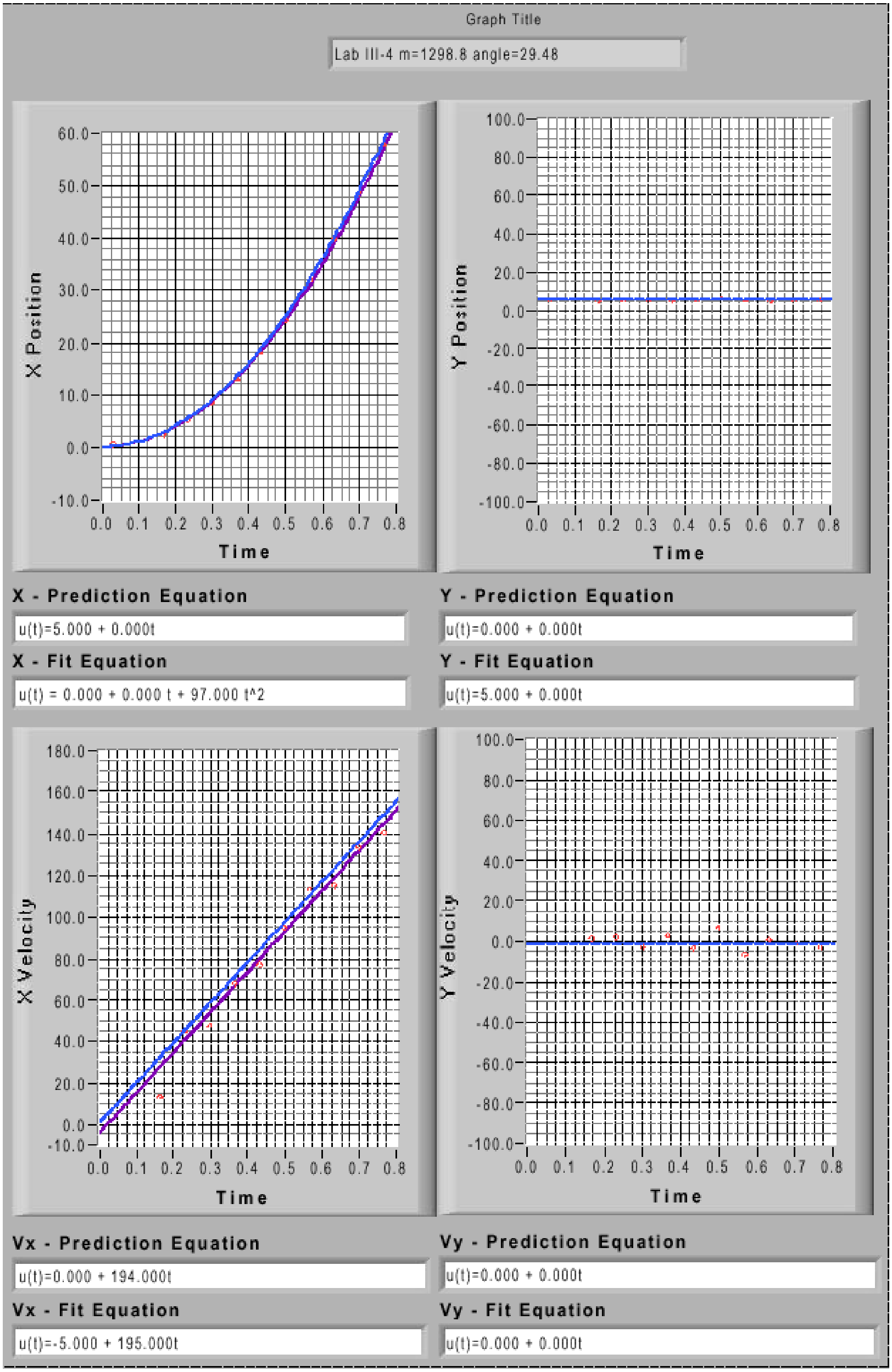
Mass of the wooden block: $m = 554.5$ (g),

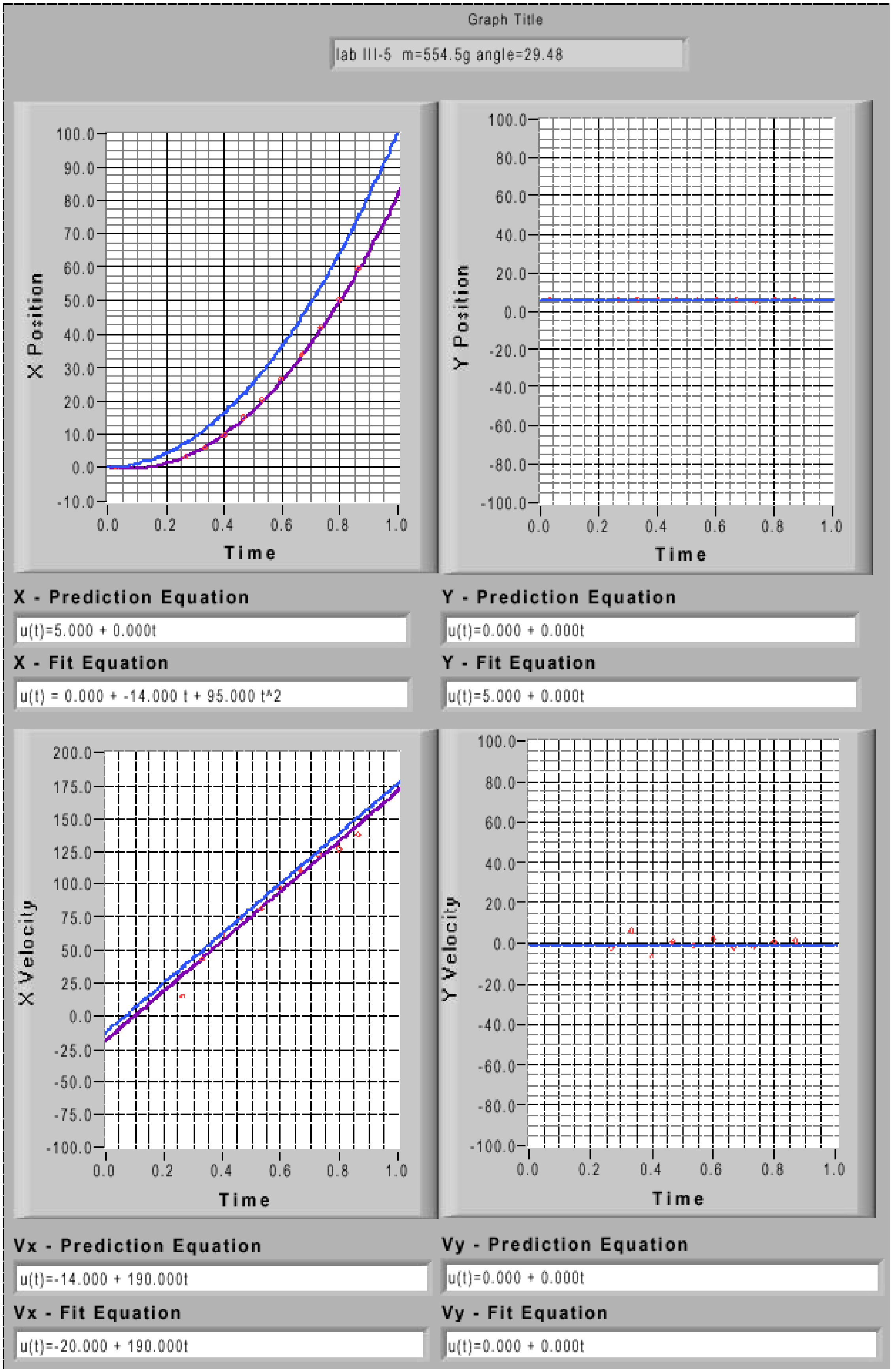
θ (^{0})	25.55	27.21	29.48	33.22
a (cm/s^2)	119.6	149.6	190	257
Normal force N (N)	4.90	4.83	4.73	4.55
Frictional force. f_k (N)	1.680	1.656	1.621	1.552

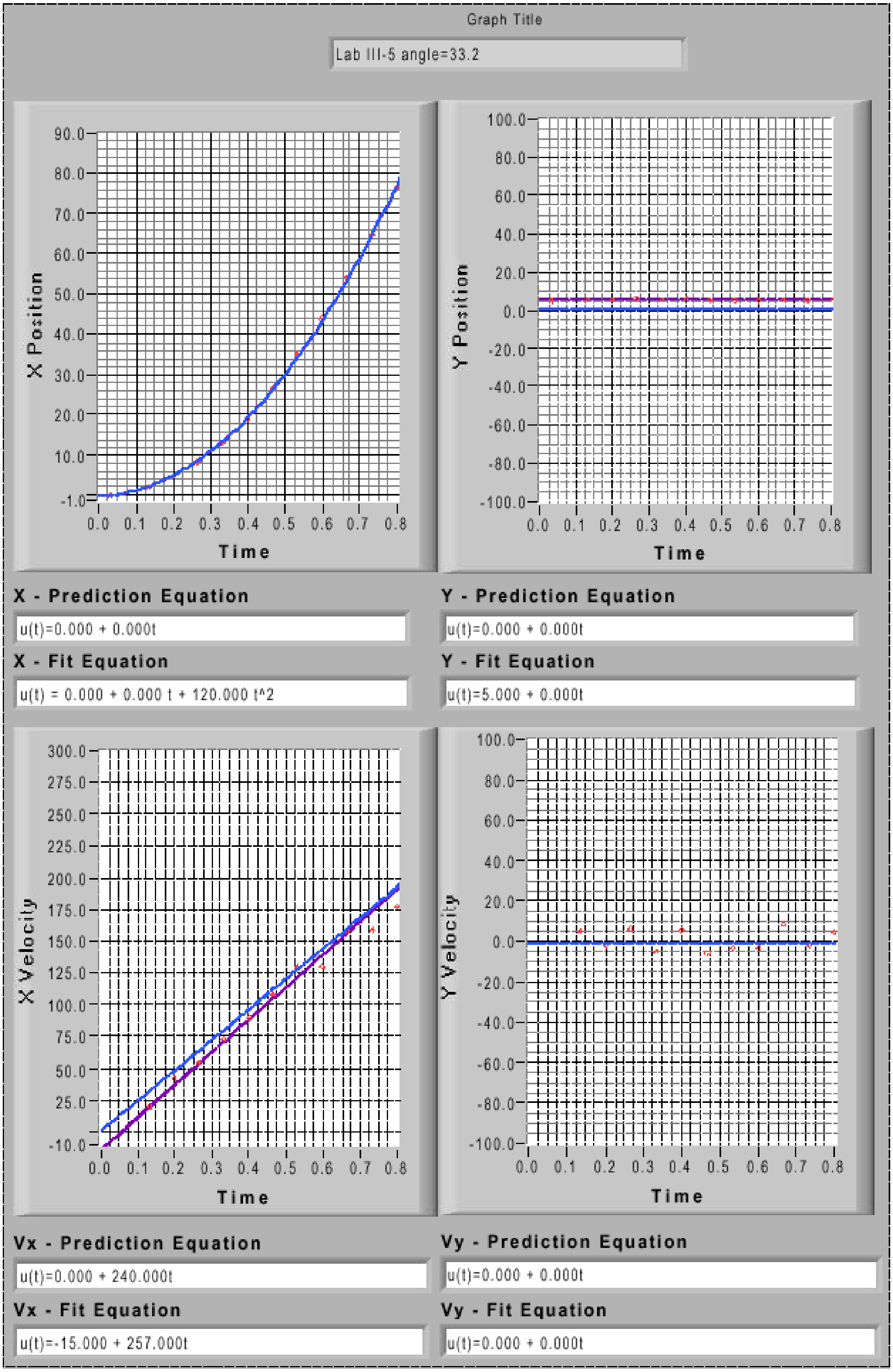


$\mu_k = 0.3665$


Graph Title
lab III-4 m=554.5g angle=29.48
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=5.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + -14.000 t + 95.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=5.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-14.000 + 190.000t
Vx - Fit Equation
u(t)=-20.000 + 190.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab III-4 m=1298.8 angle=29.48
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=5.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 97.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=5.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 194.000t
Vx - Fit Equation
u(t)=-5.000 + 195.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
lab III-5 m=554.5g angle=29.48
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=5.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + -14.000 t + 95.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=5.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-14.000 + 190.000t
Vx - Fit Equation
u(t)=-20.000 + 190.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab III-5 angle=33.2
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 120.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=5.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 240.000t
Vx - Fit Equation
u(t)=-15.000 + 257.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

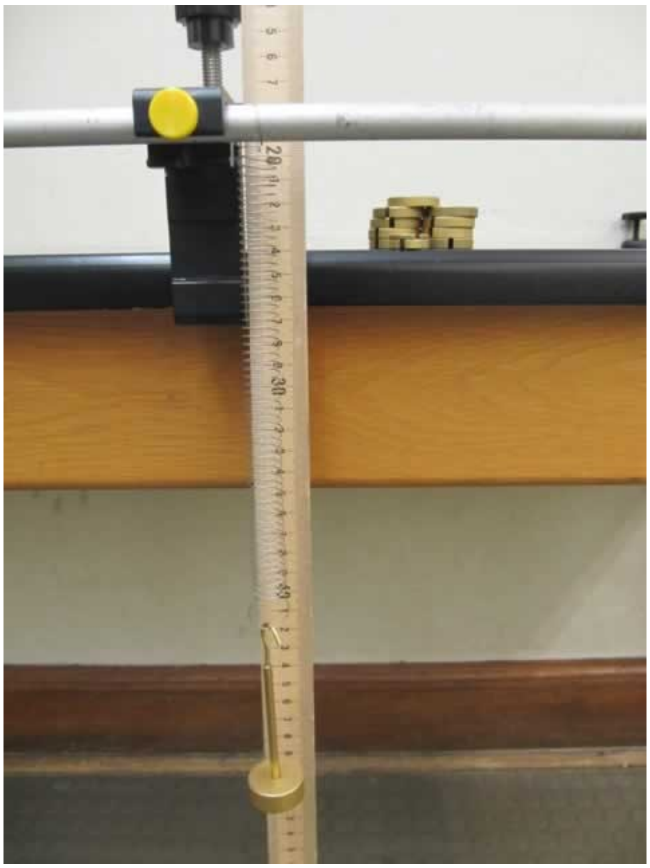
LAB 3, PROBLEM 6: MEASURING A SPRING CONSTANT – HOOKE'S LAW

PURPOSE

To familiarize students with the properties of a spring

EQUIPMENT

Spring, rod, clamp, hanging mass set, meter stick, stopwatch



TEACHING TIPS

1. Be sure not pass the elastic limit of springs. The hanging mass should be less than 200 g.

2. While measuring, fix the top of the spring. Don't let it slide along the rod.

3. Choose the reference point at the mass holder not at the spring since the spring will stretch during oscillation.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students do not realize the spring constant is a property of a spring. They may think the spring constant will change with different hanging mass.

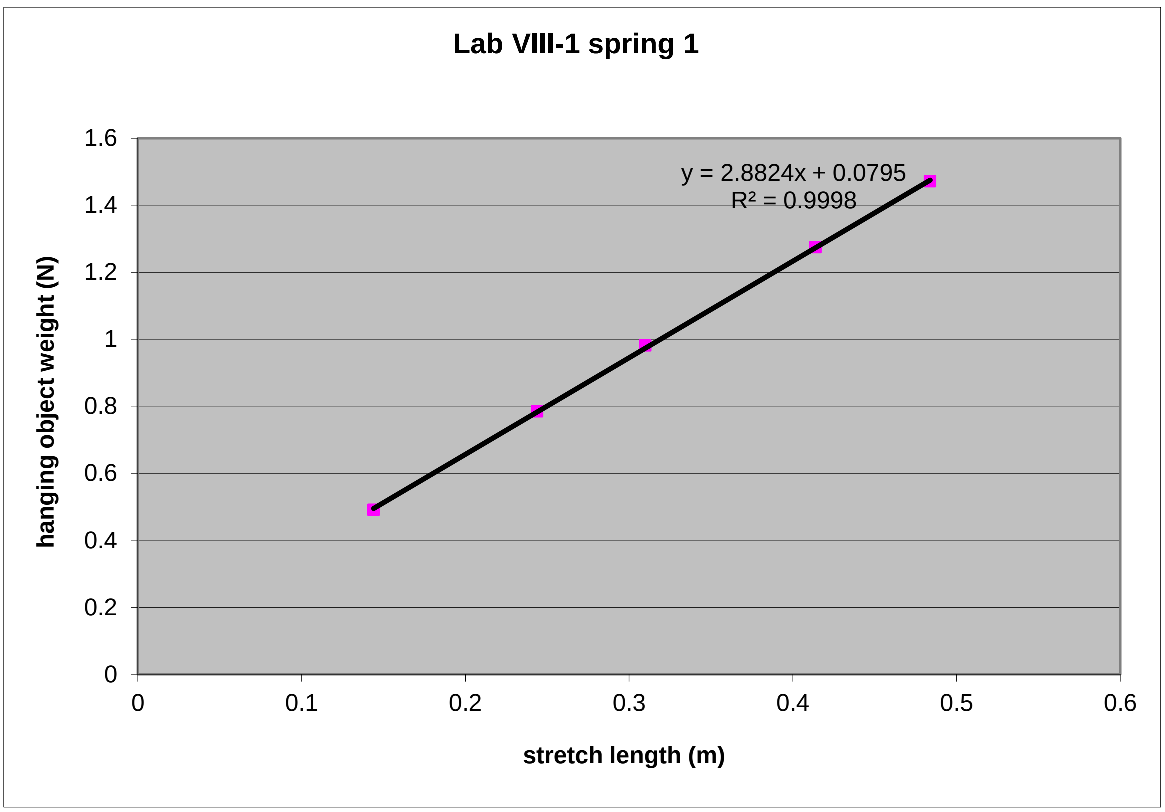
PREDICTION AND WARM-UP QUESTIONS

$f = -kx$

Sample Data

1) Spring1

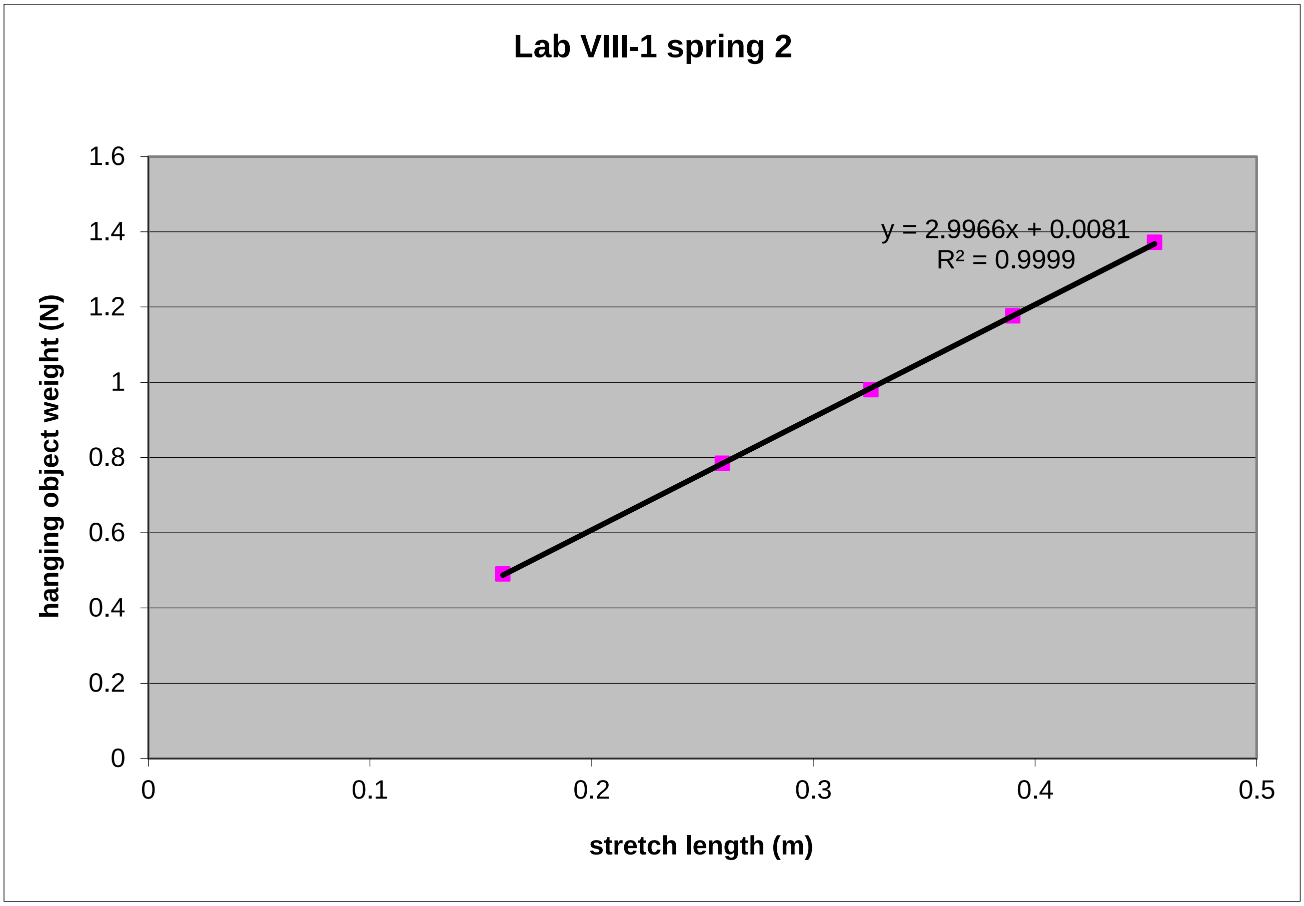
Stretch length d (cm)	14.4	24.4	31	41.4	48.4
Mass of object m (g)	50	80	100	130	150



Spring constant $k_1 = 2.882$ (N/m).

2) Spring 2

Stretch length d (cm)	16	25.9	32.6	39	45.4
Mass of object m (g)	50	80	100	120	140



Spring constant $k_2 = 2.997$ (N/m).

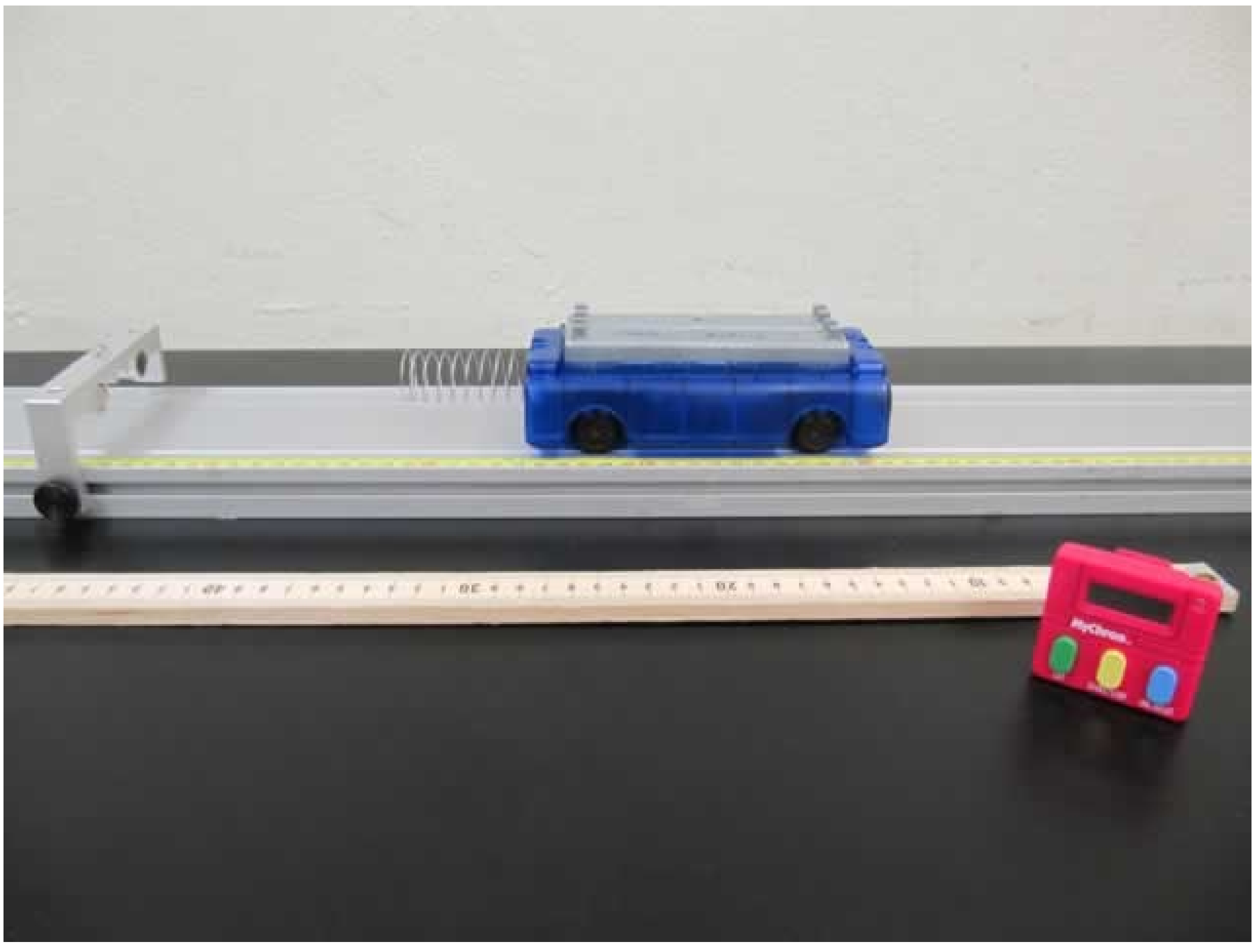
LAB 3, PROBLEM 7: FORCE, IMPULSE AND MOMENTUM

PURPOSE

Experimentally compare the two sides of the impulse-momentum theorem.

EQUIPMENT

Video analysis tool and cameras, carts with compression springs attached, meter stick to measure compression of the spring, masses for the Hooke's Law component



TEACHING TIPS

- This is a newer lab, and it has the students use the video software in two unique ways. First, they analyze the video for the information about the compression of the spring, and, second, they use the analysis software to acquire information concerning the initial and final velocities of the collision with the end.
- The videos need to be close enough to the end point that they can read the millimeter marks on the meter stick and also they need a couple of frames of the carts motion before and after. You may want to discuss what information they are getting from the videos at the beginning of lab.

- For the velocities, they do not have to put in any predictions, or even fit equations! Stop them if they are trying. Help them figure out how many data points they need in order to get one velocity reading. This trick will help them in the other momentum labs.
- For the impulse side of the equation, they may have difficulty understanding what the graph should look like so give them some help with this. The book does a decent job covering the "integral" or area under the Force vs. time curve. *Don't bring up the integral with the whole class. Individual students may know what's going on, but the class as a whole is not expected to know it.*
- The preliminary runs seem to indicate that the separate calculations are within ~10% of each other. The lab tells them to consider the change in momentum to be the "theoretical" value as it is the one with the least amount of estimation.
- The mass of the cart and the length of the collision do not appear to produce different results.
- They should use their methods of finding the spring constant that they developed in the last lab. The springs on the carts are likely the same as the compression springs. That is a good confirmation that they measured the 'k' value correctly. They can put the cart on an inclined plane and add masses to incorporate Hooke's Law but make sure they take the angle of the plane into account in their calculation.
- You could have every group write their k values on the board so that the class can determine an average deviation assuming that all of the springs have approximately the same spring constant.
- The important part about this lab is that they see the separate calculations yield the same results. Physics works like we are expecting, and everyone is happy about it.

PREDICTION AND WARM-UP QUESTIONS

Impulse:

$J = \sum F \Delta t$

Change in momentum:

$\Delta p = m\Delta v = m(v_f - v_i)$

Hooke's Law:

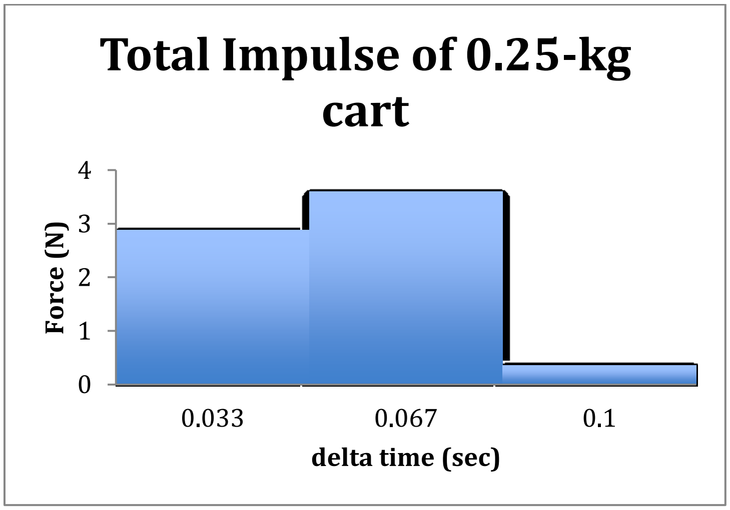
$F = k\Delta x$

SAMPLE DATA

Trial 1

Changing momentum	Mass (kg)	0.25	k-value (N/m)	
				360
	v_i (m/s)	-0.42		
	v_f (m/s)	0.42		
			Δt (sec)	
	Δp (kg*m/s)	0.21		0.033

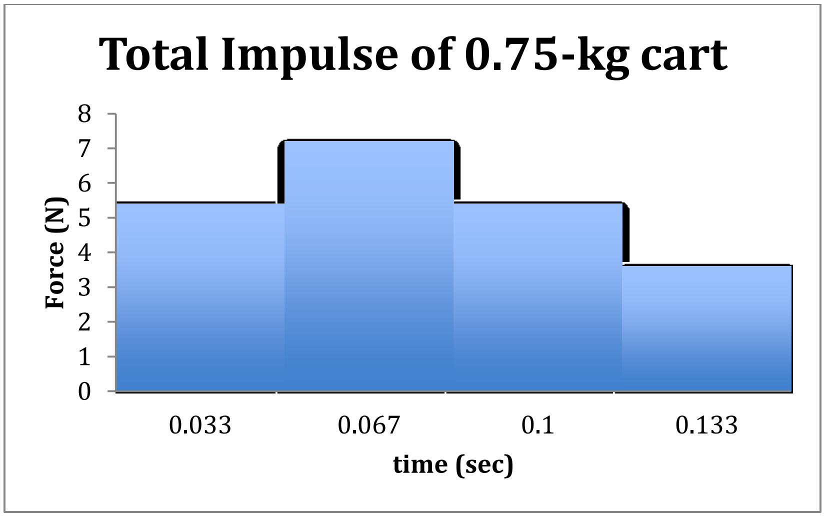
Impulse	Δ time (sec)	Δx (m)	Force (N)	Impulse (N*s)
	0.033	0.008	2.88	0.09504
	0.067	0.01	3.6	0.1188
	0.1	0.001	0.36	0.01188
				total J (N*s)
				0.22572



Trial 2

Changing momentum		
	Mass (kg)	0.75
	v_i (m/ s)	-0.41
	v_f (m/ s)	0.45
	Δ p (kg*m/ s)	0.645

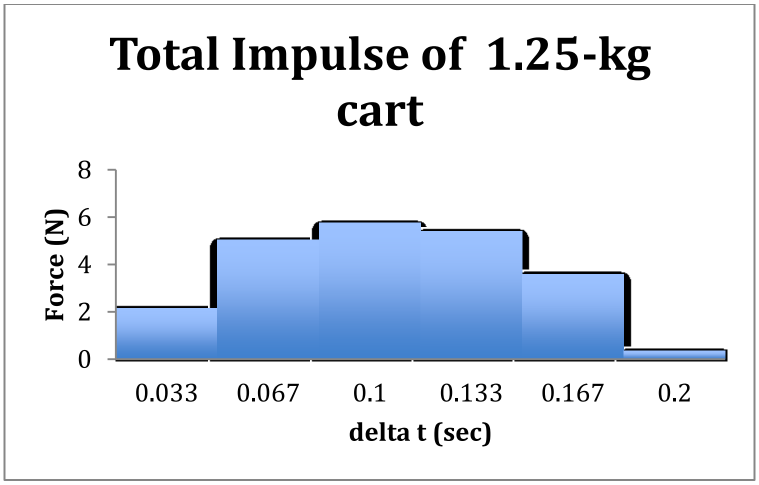
Impulse	Δ time (sec)	Δ x (m)	Force (N)	Impulse (N*s)
	0.033	0.015	5.4	0.1782
	0.067	0.02	7.2	0.2376
	0.1	0.015	5.4	0.1782
	0.133	0.01	3.6	0.1188
				total J (N*s)
				0.7128



Trial 3

Changing momentum	Mass (kg)	1.25		
	v_i (m/ s)	-0.29		
	v_f (m/ s)	0.29		
	Δ p (kg*m/ s)	0.725		

Impulse	Δ time (sec)	Δ x (m)	Force (N)	Impulse (N*s)
	0.033	0.006	2.16	0.07128
	0.067	0.014	5.04	0.16632
	0.1	0.016	5.76	0.19008
	0.133	0.015	5.4	0.1782
	0.167	0.01	3.6	0.1188
	0.2	0.001	0.36	0.01188
				total J (N*s)
				0.73656



Possible Discussion Questions:

1) Do you expect a difference in accuracy if you changed the mass of the cart? How about the length of the collision time? What combination of the two would you expect to be the best?

What is the expected uncertainty associated with the impulse estimation? What is the expected uncertainty associated with the change in momentum measurement?

TA Lab Evaluations

Physics 1301 Lab 3: Forces

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to **labhelp@physics.umn.edu**, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

____

____

____

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

____

Do you have additional comments regarding student learning and these labs?

____

____

____

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room

Was the room kept neat and clean by your class and other classes? (circle one) yes / no

Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

____

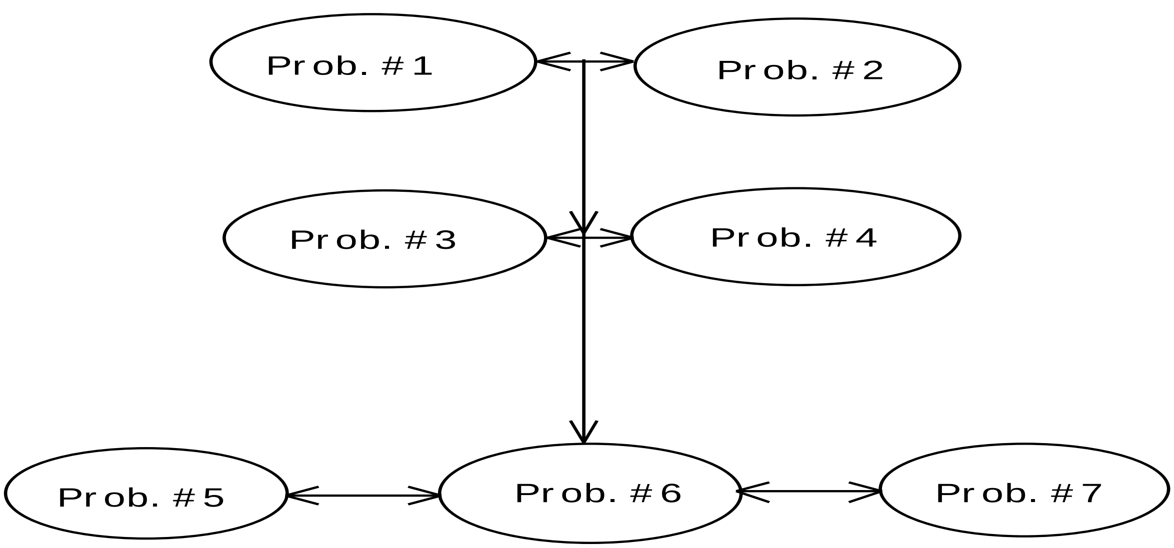
____

____

LABORATORY 4: DESCRIPTION OF MOTION IN TWO DIMENSIONS

This lab is basically a continuation of Laboratory 1. It is taught so much later so that the concepts in Laboratories 2 and 3 were not obfuscated by the additional complication of a second dimension. Now that the students understand those concepts, we want them to continue developing their understanding of position, displacement, time, velocity, and acceleration. You should also continue to point out the differences between instantaneous and average quantities. We want the students to understand that 2-D motion can be described as two independent, perpendicular 1-D motions of the same object. This is a difficult concept for your students.

Problems #1 and #2 should familiarize your students with strictly vertical motion, as well as help them see what assumptions can be made when carrying out these problems. The mass effect is present, but really quite difficult to detect (unless you use the Styrofoam balls). Problems #3 and #4 are traditional 2-D motion. Problem #5 is an introduction to circular motion as another example of 2-D motion. It also shows that an object with a constant speed can be accelerating. Problem #6 should serve to show students that vectors can be useful to gain a qualitative understanding of problems. Problem #7 allows students to explore how the acceleration of an object in uniform circular motion depends on its radius and its speed.



BY THE END OF THIS LAB, STUDENTS 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 of motion, and 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 of motion, and by considering what quantities and initial conditions affect the motion.

THINGS TO CHECK OUT BEFORE TEACHING THIS LAB

- Check every wheel for every plastic cart to see if the wheel can continue rotating at least two seconds by a gentle push.
- Find a friend and try out the labs concerning projectile motion and the bouncing ball; get an idea of how hard you can throw the various objects to get a good movie. This experience will allow you to help your students when they cannot get a good movie.
- Make sure that you review how to change all of the adjustments of the camera so you can help a group who cannot get their camera to take a good movie.

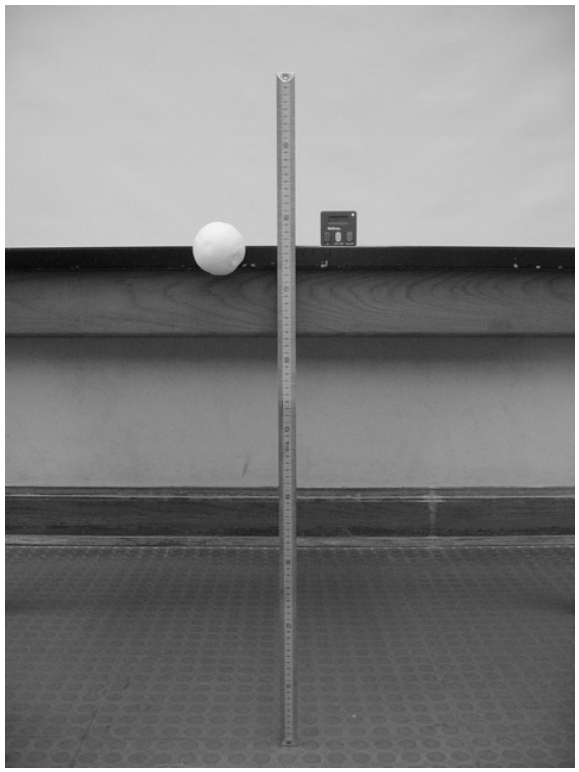
Lab 4, Problem 1: Projectile Motion and Velocity

Purpose

- To show the students that two-dimensional motion can be treated as two separate one-dimensional problems describing the motion of the object simultaneously.

Equipment

Balls, meter stick, stopwatch



Teaching Tips

- This is a great lab for the students to practice decomposing vectors. This is difficult for most of them to accept intellectually and they need the practice.
- Parallax does influence the outcome of the movie analysis. It can skew the results by 10%, or even more if the students are not thoughtful about their movie making. The parallax issue is why the students are asked to use the object in motion to calibrate their computers. Shadows and image resolution may prevent an accurate calibration from the balls in flight. In this case, the students should put an object of known length **in the plane of motion**.

- The students' lab manual tells them to "make a video of a ball thrown in a manner appropriate to juggling." You may want to make this clearer by pointing out that we just want them to toss it to a lab partner, hopefully with a rather high arc to make the analysis more interesting. We certainly don't envision the students analyzing an actual juggled ball!

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students have difficulty with two-dimensional motion. Part of this difficulty is mathematical in nature (i.e., solving systems of equations), but most of it is physics. The concept that horizontal and vertical motions are independent is difficult. Be on the lookout for students who draw V-shaped velocity-time graphs.

PREDICTION AND WARM-UP QUESTIONS

The horizontal and vertical positions and velocities are given by:

$$x(t) = v_{ix}t, \qquad v_x(t) = v_{ix},$$

$$y(t) = v_{iy} - \tfrac{1}{2}gt^2, \qquad v_y(t) = v_{iy} - gt,$$

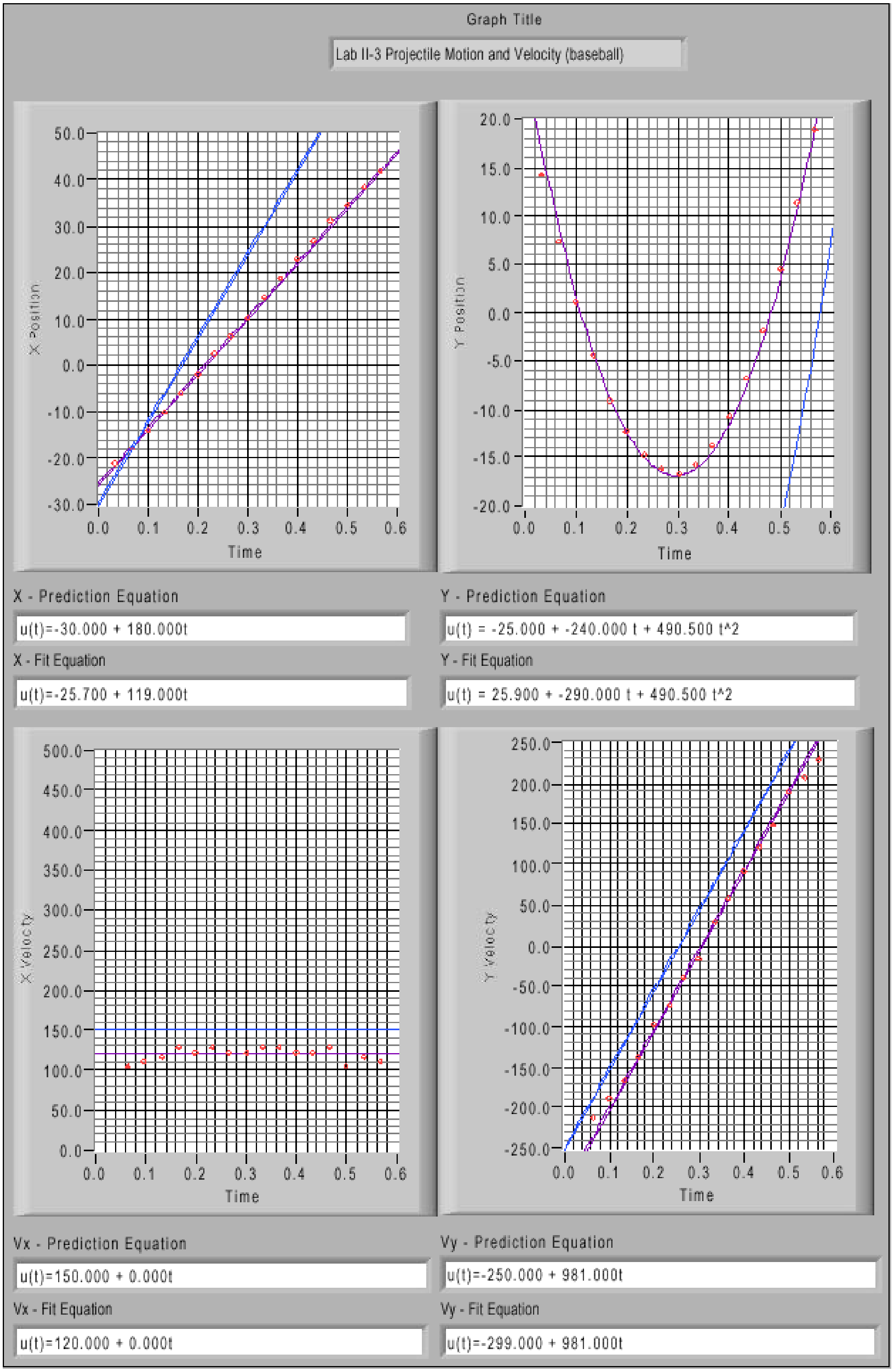
where v_{ix} is the horizontal component of the initial velocity, v_{iy} is the vertical component of the initial velocity, and the initial position of the ball is taken to be the origin of the coordinate system.

SAMPLE DATA

The printouts for all measurements are included at the end of following sample data.

Using baseball: mass = 144.50g, diameter = 7.40cm.

The motion along X (horizontal) axis is a constant velocity motion with velocity 119 cm/s, and the motion along Y (vertical) axis is a constant acceleration motion with acceleration 981 cm/s^2, with the defined positive directions for both axes.


Graph Title
Lab II-3 Projectile Motion and Velocity (baseball)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-30.000 + 180.000t
X - Fit Equation
u(t)=-25.700 + 119.000t
Y - Prediction Equation
u(t) = -25.000 + -240.000 t + 490.500 t^2
Y - Fit Equation
u(t) = 25.900 + -290.000 t + 490.500 t^2
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=150.000 + 0.000t
Vx - Fit Equation
u(t)=120.000 + 0.000t
Vy - Prediction Equation
u(t)=-250.000 + 981.000t
Vy - Fit Equation
u(t)=-299.000 + 981.000t

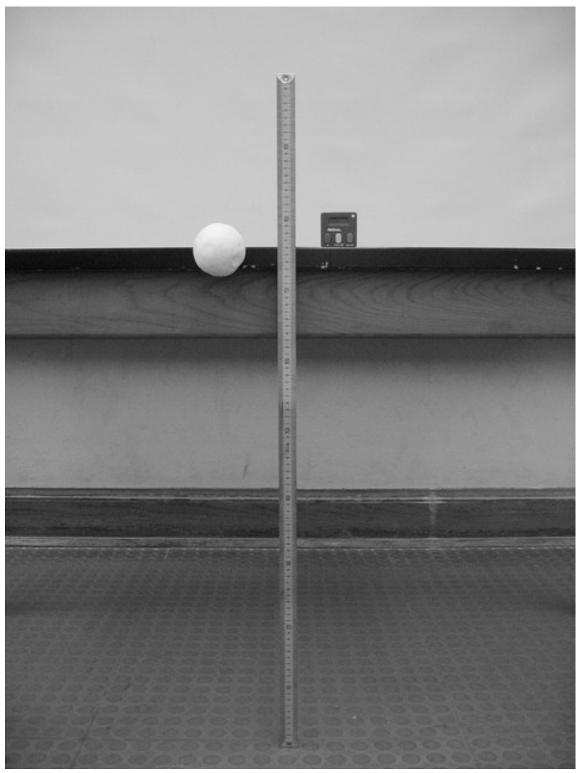
LAB 4, PROBLEM 2: BOUNCING

PURPOSE

- This is the first of the true problem-solving labs. Point out the difference to your students. Tell them of the new and higher expectations involved in getting the equations for their predictions as opposed to using an "educated guess" to predict the relevant physics quantity.

EQUIPMENT

Ball, meter stick, stopwatch



TEACHING TIPS

- *This is a very difficult lab*. If the students are not careful about how they do their analysis, they can very easily get incorrect results. However, if they are careful, it works out very nicely.
- The object being used to calibrate the movie MUST be in the plane of the bouncing ball. (We placed a box of known length on the floor in the center of the screen.) If the ball bounces in front of or behind this plane, their results will not come out correct to within 10%. Tell the students to practice bouncing the ball and be patient about getting a good movie.

- Again, it is very important that all bounces that are recorded are in the same plane of motion within a movie. The balls have a tendency to move a bit towards or away from the camera after each bounce. The camera CANNOT take the third dimension into account, so the students' results will not be correct.
- It is also quite important that the students click on the same point of the ball throughout the entire movie (as is the case in all of the problems!). If they click on the bottom of the ball at the top of the motion, and the top of the ball right before it bounces, the height they measure could be off by as much as a few centimeters. Make sure that they are consistent.
- Make sure that the students capture all of the motion of the ball within the area of the screen, including the bounces. The students should be especially concerned with where their origin is, to ensure that they are measuring the correct height and horizontal distance. We found the data tables useful for finding the height of the bouncing ball.
- It works well to analyze both bounces at once. Then it is quite clear that the initial horizontal velocity remains constant throughout the bouncing. However, the students will have to be careful about where the origin is, as mentioned above.
- This is a good lab to help the students think about the uncertainty in position in their movies. The equation that they will use is not that difficult, so this is a good opportunity to check that they understand how to propagate uncertainty through equations according to the lab manual appendix.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The alternative conceptions of students are the same as in Problem #3. Students need a lot of repetition emphasizing the independence of perpendicular components of motion.

PREDICTION AND WARM-UP QUESTIONS

$$\frac{x_0}{x_1} = \frac{v_{ox}}{v_{1x}}\sqrt{\frac{h_o}{h_1}},$$

where h_o is the height of the first bounce, h_1 is the height of the second bounce, x_o is the horizontal distance of the first bounce, x_1 is the horizontal distance of the second bounce, v_{ox} is the initial horizontal velocity during the first bounce and v_{1x} is the initial horizontal velocity during the second bounce. Your students should find in their analysis that $v_{ox}=v_{1x}$, thus they cancel out of the above equation. This is a very interesting and surprising result, which they should wonder about. (Refer to this again when they study forces and Newton's second law. During the bounce, the force on the ball caused by the floor is vertical so only the vertical component of velocity can change. **Do not**, however, lecture to them about it.)

SAMPLE DATA

The printouts for the measurements of all distances and velocities are included at the end of following sample data.

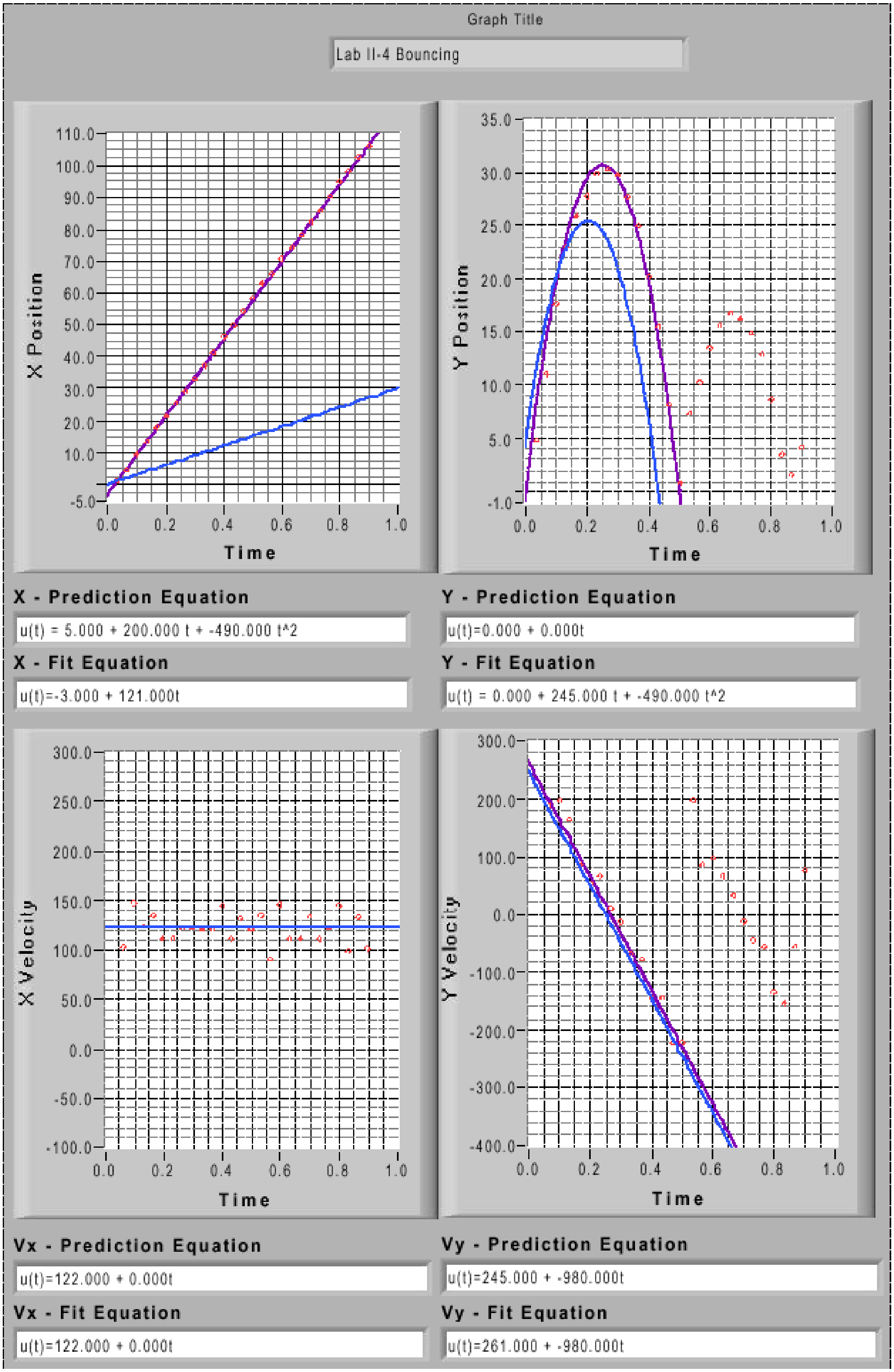
$v_{0x} = v_{1x} = 121$ (cm/s),

$x_0 = 58.5$ (cm), $x_1 = 44.5$ (cm),

$h_0 = 29.8$ (cm), $h_1 = 16.2$ (cm),

Predicted $\frac{x_0}{x_1}$ =1.356,

Measured $\frac{x_0}{x_1}$ =1.315.


Graph Title
Lab II-4 Bouncing
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 5.000 + 200.000 t + -490.000 t^2
X - Fit Equation
u(t)=-3.000 + 121.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.000 + 245.000 t + -490.000 t^2
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=122.000 + 0.000t
Vx - Fit Equation
u(t)=122.000 + 0.000t
Vy - Prediction Equation
u(t)=245.000 + -980.000t
Vy - Fit Equation
u(t)=261.000 + -980.000t

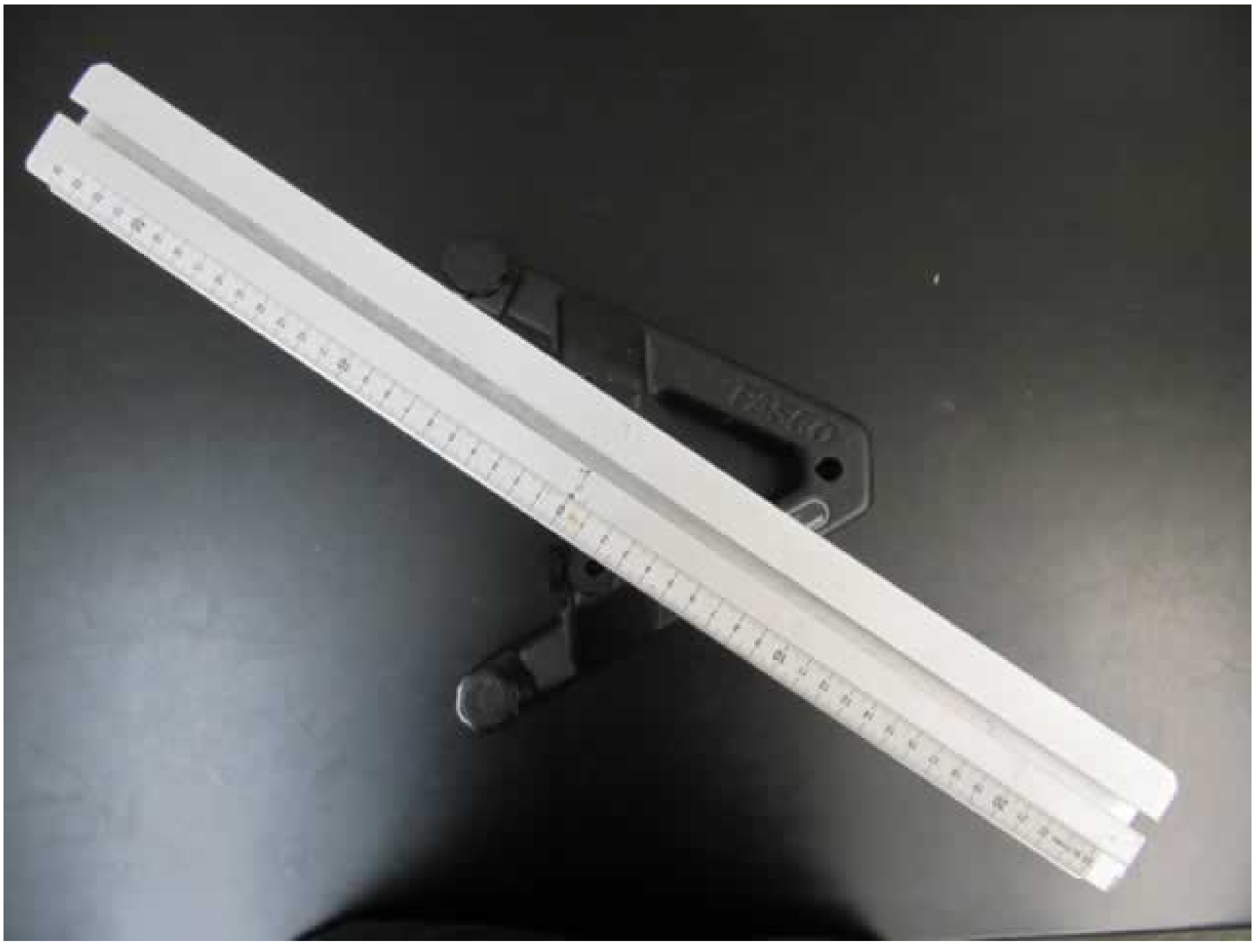
LAB 4, PROBLEMS 3–5

PURPOSE

- To show students that objects with constant speed can be accelerating. To give an example of 2-D motion with non-constant acceleration.

EQUIPMENT

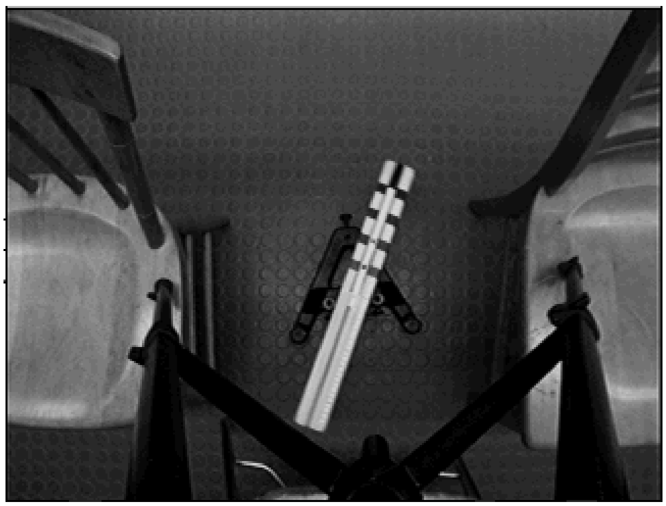
Rotating bar on base



TEACHING TIPS

- Your students will find these problems challenging since most students do not yet understand vectors or kinematics well. Try to let them work on it on their own before stepping in to help. They generally just assume that the velocity is tangent to the circle, because the book says so. They do not appreciate that they can understand this "complicated" motion using just the definitions of velocity and acceleration.

- To convince the students that the velocity vectors are tangent to the circle, they must first recognize that the position vectors are the radius vectors. The difference in position gives the direction of the average velocity between the two position vectors. A limiting process of bringing those two position vectors closer together gives the direction of the instantaneous velocity.
- For Problem 7, **do not lecture** about gravitational force. The students don't need to understand it to do the problem.
- Below is a frame from a "good movie." Notice that the camera is mounted directly above the center of the spinning apparatus. There is very little clutter, the picture is clear, and the contrast is about right. If you could see the entire movie, you would find that the arm is visible at all points of the movie.



- To get these problems to work properly the students **must** use the arm of the spinning apparatus to calibrate their movie. When we analyzed the movie (a frame of which is shown on the previous page) we found that when we used the base of the apparatus for calibration our best fit was $y(t) = 78.1 + 12.8\sin(2.7t + 1.89)$. When we used the arm for calibration the best fit was $y(t) = 62.9 + 10.2\sin(2.7t + 1.89)$. The radius at which we did the analysis was supposed to be 10 cm.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students do not believe that an object moving at a constant speed can be accelerating especially toward the center of the circle. Again, you will come up against the misconception that the acceleration must be in the direction that the object is moving. If they have read the book (or remember high school physics) they might believe that the acceleration points inward as a matter of faith. They don't understand that the same definitions they used for linear motion will get them to this result when the magnitude of the velocity isn't changing but the direction is.

Students also may believe there is an outward acceleration, based on their personal experience with circular motion.

PREDICTIONS AND WARM-UP QUESTIONS

Problem 3:

$$x = x_c + r\sin(\omega t + \theta_0), \qquad y = y_c + r\cos(\omega t + \theta_0),$$

$$v_x(t) = \omega r\cos(\omega t + \theta_0), \qquad v_y(t) = -\omega r\sin(\omega t + \theta_0),$$

$$a_x(t) = -\omega^2 r\sin(\omega t + \theta_0), \qquad a_y(t) = -\omega^2 r\cos(\omega t + \theta_0),$$

$$a = \omega^2 r,$$

Problem 4: The acceleration is directed radially towards the center of the circular orbit.

Problem 5: $a = \dfrac{4\pi^2 r}{T^2}$, (since $a = \omega^2 r$ and $T = \dfrac{2\pi}{\omega}$).

(Here x_c and y_c are position components for the center of the circular orbit, θ_0 is the initial angle that the object makes with the x-axis, r is the radius of the circle, and ω is the constant angular speed, T is the period of the orbit.)

SAMPLE DATA

The printouts for all measurements are included at the end of following sample data.

Problem 3:

Measured angular speed: 2.93 (rad/s),

Measured radius of rotation: 12.2 (cm),

Acceleration: $a = 104.6$ (cm/s²)

Problem 4:

The data are based on the exported data from MotionLab.

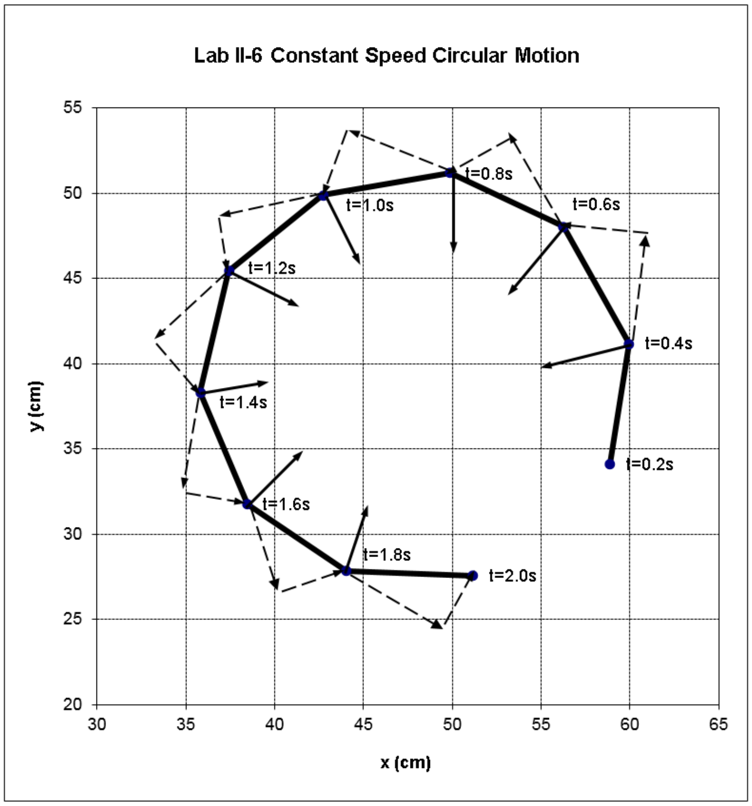
Time (s)	X (cm)	Y (cm)	Time (s)	X (cm)	Y (cm)
0.2	58.886	34.129	2.6	58.886	44.896
0.4	59.947	41.22	2.8	53.846	49.886

0.6	56.233	48.048	3	46.95	51.724
0.8	49.867	51.199	3.2	40.584	48.836
1	42.706	49.886	3.4	36.339	43.321
1.2	37.4	45.422	3.6	36.074	36.493
1.4	35.809	38.331	3.8	39.523	30.453
1.6	38.461	31.766	4	45.358	27.826
1.8	44.032	27.826	4.2	52.255	27.826
2	51.194	27.564	4.4	57.825	31.766
2.2	57.029	31.503	4.6	59.947	38.068
2.4	59.682	37.806	4.8	58.621	44.896

Measured angular speed: 2.93 rad/s

Measured radius of rotation: 12.2 cm

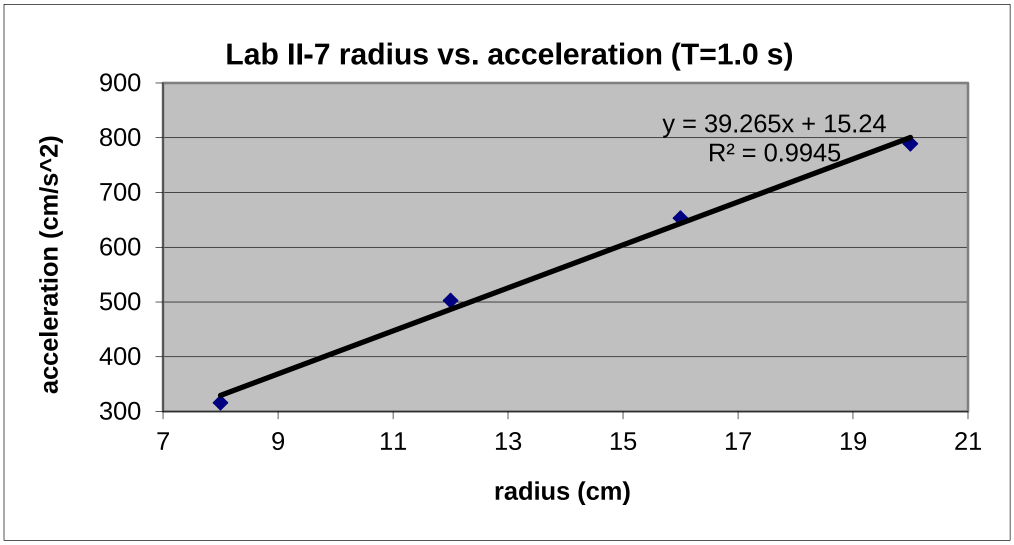
The direction of acceleration for each data point is shown in the following chart. All acceleration vectors point to the center.



Problem 5:

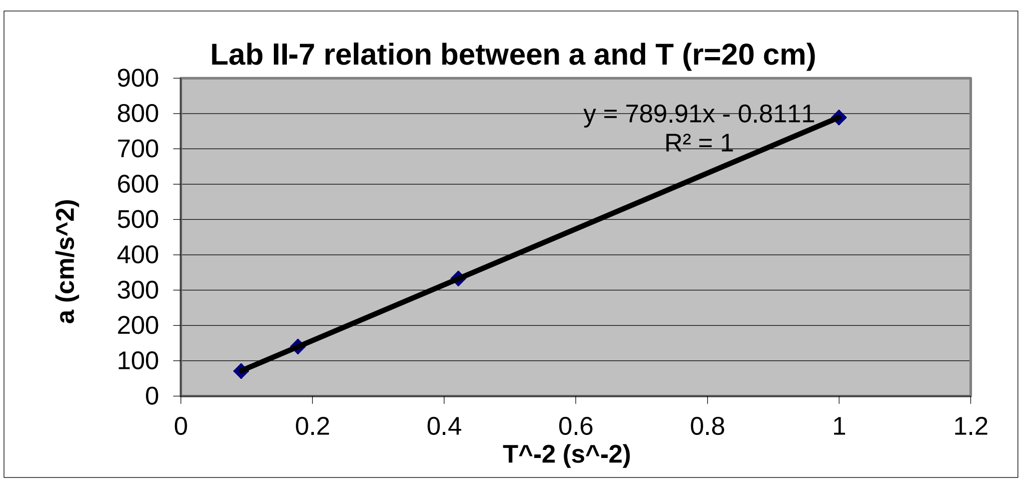
1.) T=1.0(s)

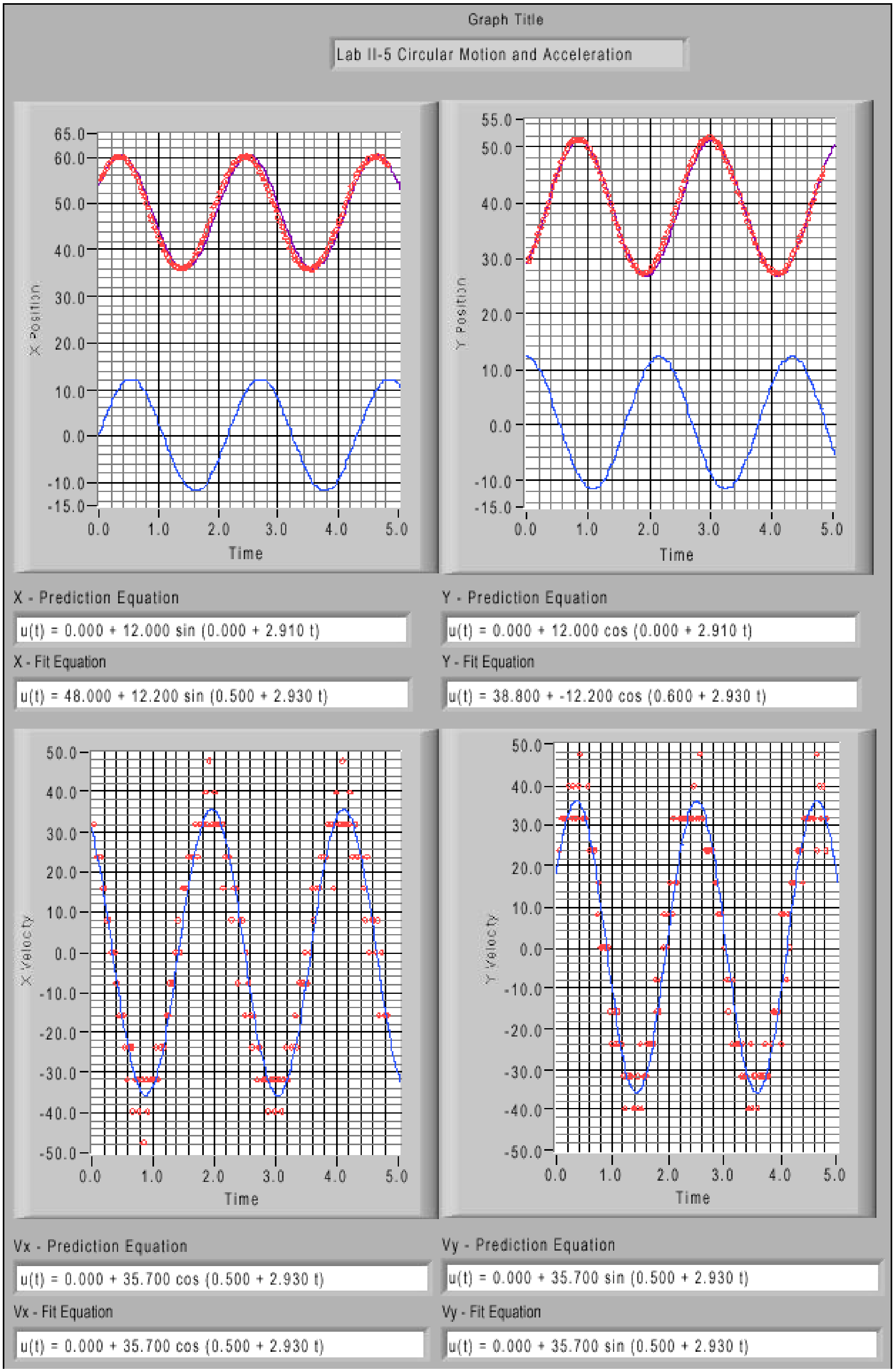
r (cm)	8	12	16	20
a (cm/s^2)	315.5	502.4	653.1	788.8

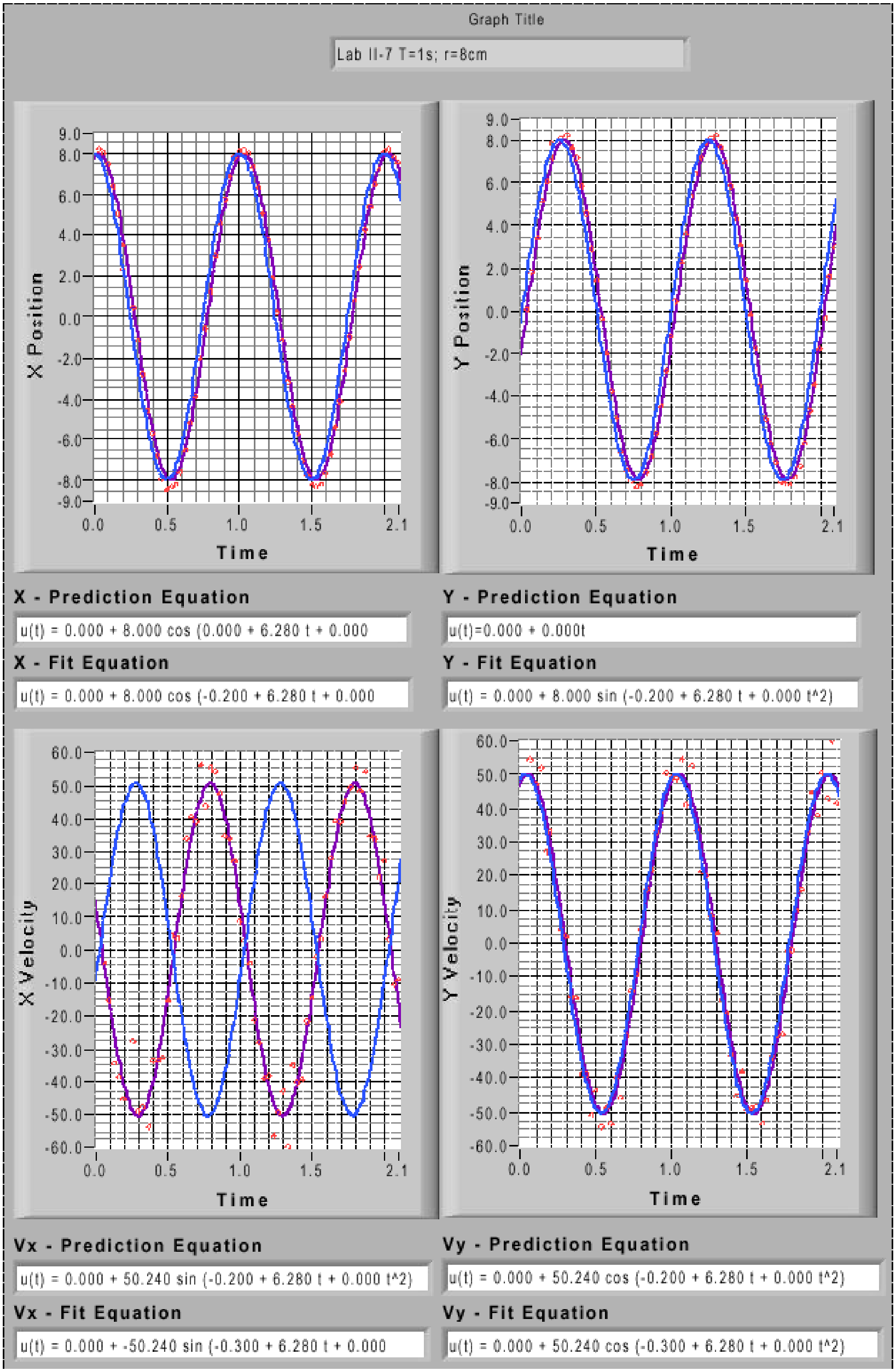


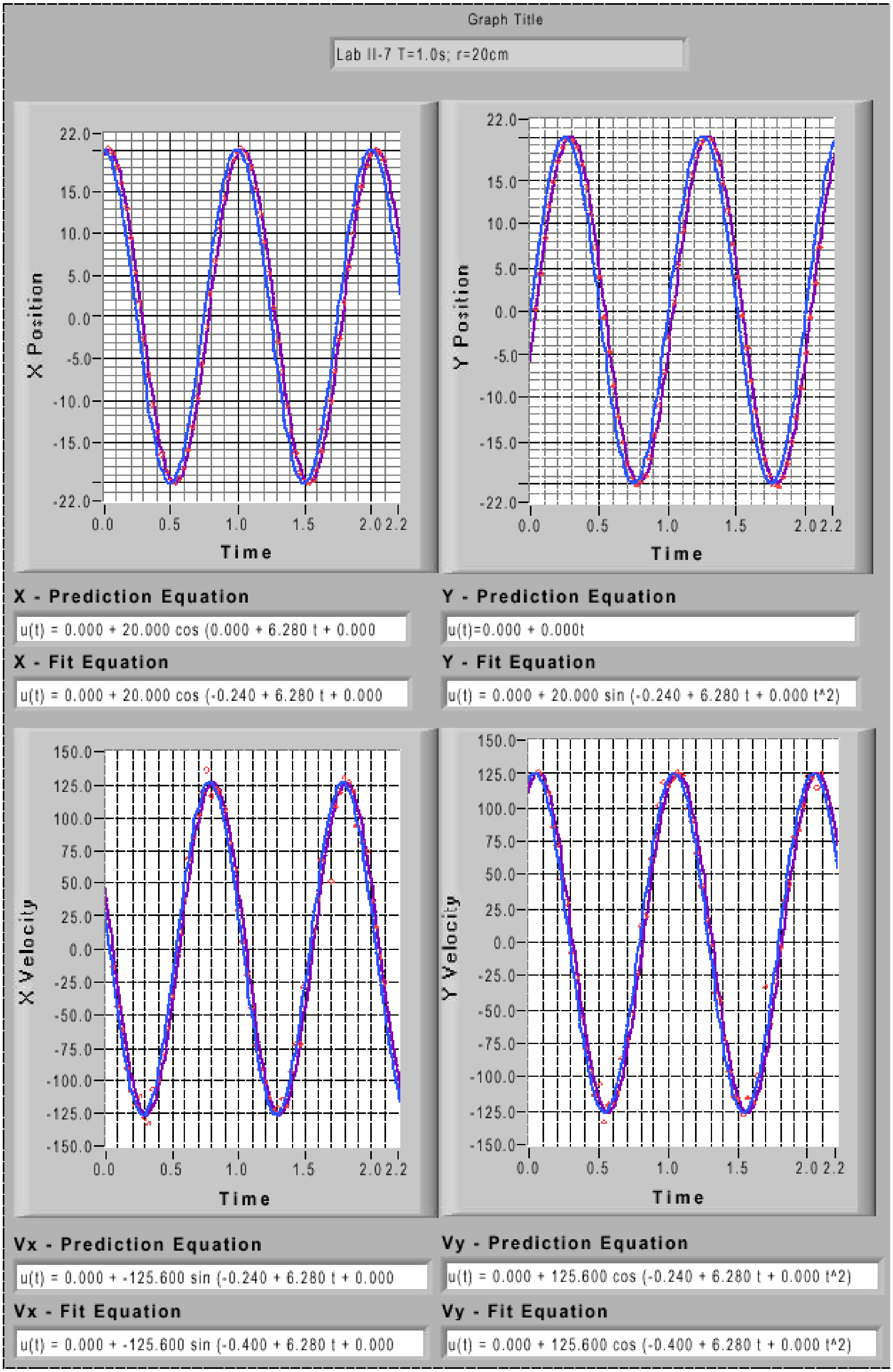
2.) r =20(cm)

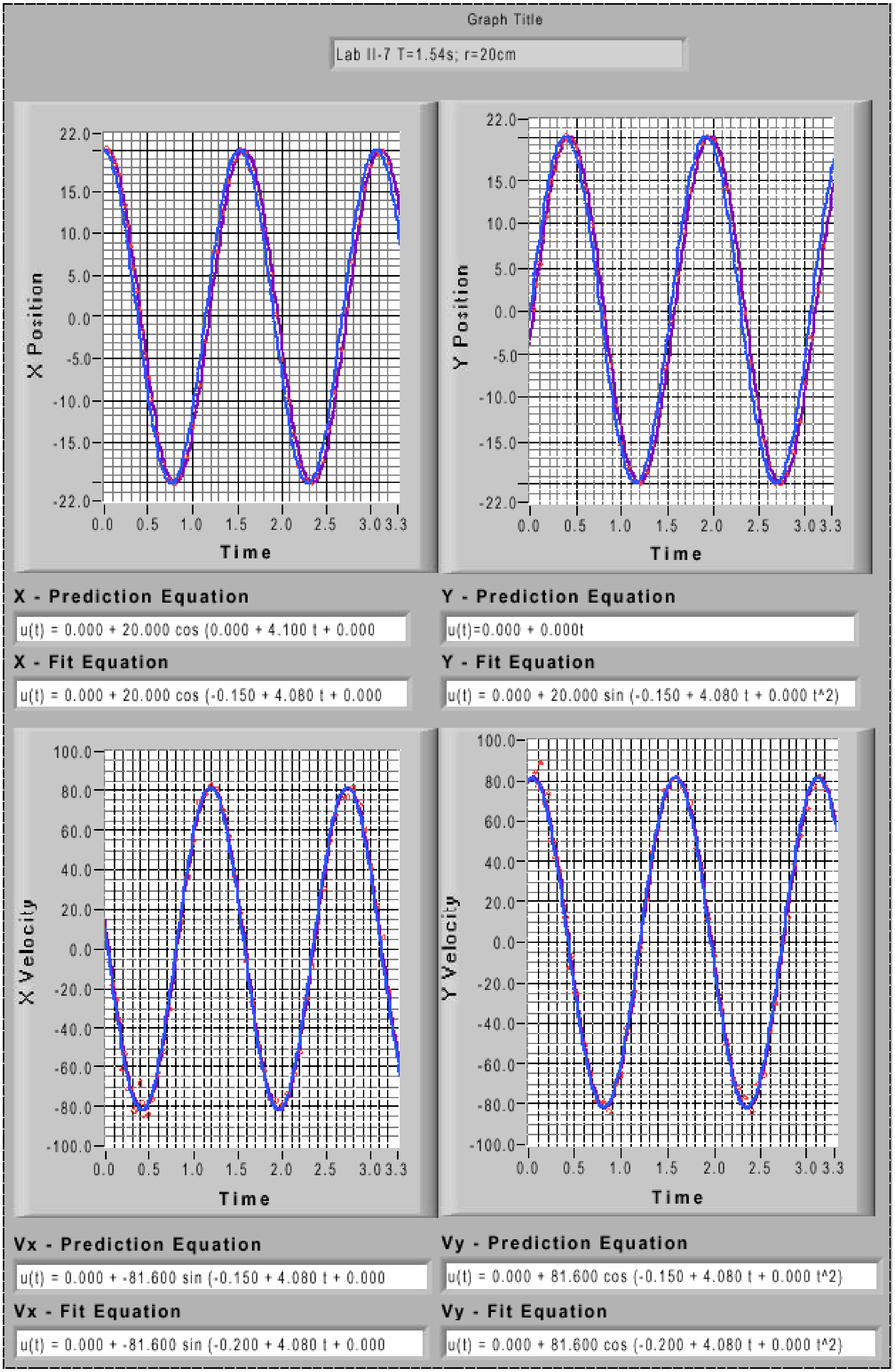
T (s)	1	1.54	2.37	3.3
T^{-2} (s^{-2})	1	0.422	0.178	0.092
a (cm/s^2)	788.8	332.9	140.5	70.7




Graph Title
Lab II-5 Circular Motion and Acceleration
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 12.000 sin (0.000 + 2.910 t)
X - Fit Equation
u(t) = 48.000 + 12.200 sin (0.500 + 2.930 t)
Y - Prediction Equation
u(t) = 0.000 + 12.000 cos (0.000 + 2.910 t)
Y - Fit Equation
u(t) = 38.800 + -12.200 cos (0.600 + 2.930 t)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 35.700 cos (0.500 + 2.930 t)
Vx - Fit Equation
u(t) = 0.000 + 35.700 cos (0.500 + 2.930 t)
Vy - Prediction Equation
u(t) = 0.000 + 35.700 sin (0.500 + 2.930 t)
Vy - Fit Equation
u(t) = 0.000 + 35.700 sin (0.500 + 2.930 t)


Graph Title
Lab II-7 T=1s; r=8cm
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 8.000 cos (0.000 + 6.280 t + 0.000
X - Fit Equation
u(t) = 0.000 + 8.000 cos (-0.200 + 6.280 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.000 + 8.000 sin (-0.200 + 6.280 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 50.240 sin (-0.200 + 6.280 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -50.240 sin (-0.300 + 6.280 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 50.240 cos (-0.200 + 6.280 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + 50.240 cos (-0.300 + 6.280 t + 0.000 t^2)


Graph Title
Lab II-7 T=1.0s; r=20cm
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 20.000 cos (0.000 + 6.280 t + 0.000
X - Fit Equation
u(t) = 0.000 + 20.000 cos (-0.240 + 6.280 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.000 + 20.000 sin (-0.240 + 6.280 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -125.600 sin (-0.240 + 6.280 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -125.600 sin (-0.400 + 6.280 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 125.600 cos (-0.240 + 6.280 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + 125.600 cos (-0.400 + 6.280 t + 0.000 t^2)


Graph Title
Lab II-7 T=1.54s; r=20cm
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 20.000 cos (0.000 + 4.100 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 20.000 cos (-0.150 + 4.080 t + 0.000
Y - Fit Equation
u(t) = 0.000 + 20.000 sin (-0.150 + 4.080 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -81.600 sin (-0.150 + 4.080 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 81.600 cos (-0.150 + 4.080 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -81.600 sin (-0.200 + 4.080 t + 0.000
Vy - Fit Equation
u(t) = 0.000 + 81.600 cos (-0.200 + 4.080 t + 0.000 t^2)

TA Lab Evaluations

Physics 1301 Lab 4: Description of Motion in Two Dimensions

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to **labhelp@physics.umn.edu**, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

Do you have additional comments regarding student learning and these labs?

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

Lab Room

Was the room kept neat and clean by your class and other classes? (circle one) yes / no

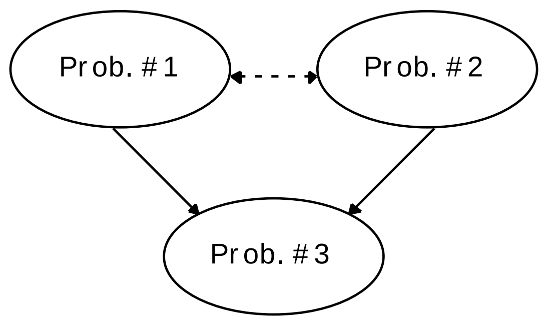
Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

LABORATORY 5: ROTATIONAL KINEMATICS

The purpose of this lab is to familiarize the students with the link between linear and rotational motions. As you probably know, rotational kinematics is a very elusive concept the first time around. It is good to discuss it with analogies to 1D kinematics. This lab also should help the students see some of the connections between linear velocity, angular velocity, linear acceleration, tangential acceleration, and centripetal acceleration. They should also be able to identify the relationships between linear motion and rotational motion.

By looking at the flow chart you can see that only two problems are required in this lab. Problems #1 and #2 are very similar – your students probably do not have to do both of these, unless they are having difficulties understanding the concepts of Problem #1.



BY THE END OF THIS LAB, YOUR STUDENTS SHOULD BE ABLE TO

- Relate the concepts of linear velocity, linear acceleration, angular speed, and angular acceleration for rigid bodies.

THINGS TO CHECK OUT BEFORE TEACHING THIS LAB

- Check wheels on the carts to see if they spin freely.
- It is very important to get a flat camera angle. The masses should fall in a plane perpendicular to the camera angle. Placing the setup on a stable chair on the table worked well.
- Make sure you know how the spool setup works.
- For Problem #2, there are two ways of performing the experiment, as described in the exploration: (i) By pushing the cart so that it unwinds the string from the ring at a constant rate; (ii) By spinning the disk so that the string winds up on the ring, pulling the cart at a constant speed. You may need to tilt the track in each of these cases, since it is important that the string remains taut at all times. You should test this out in both cases before you teach the lab, so that you can most effectively help the students if needed.
- For Problem #3, it's good to try attaching some string and masses to the different setups to see what masses work. Too much mass will cause the string to break at the spool. When

they are performing the exploration, encourage your students to increase the mass in reasonable amounts (about 100 g).

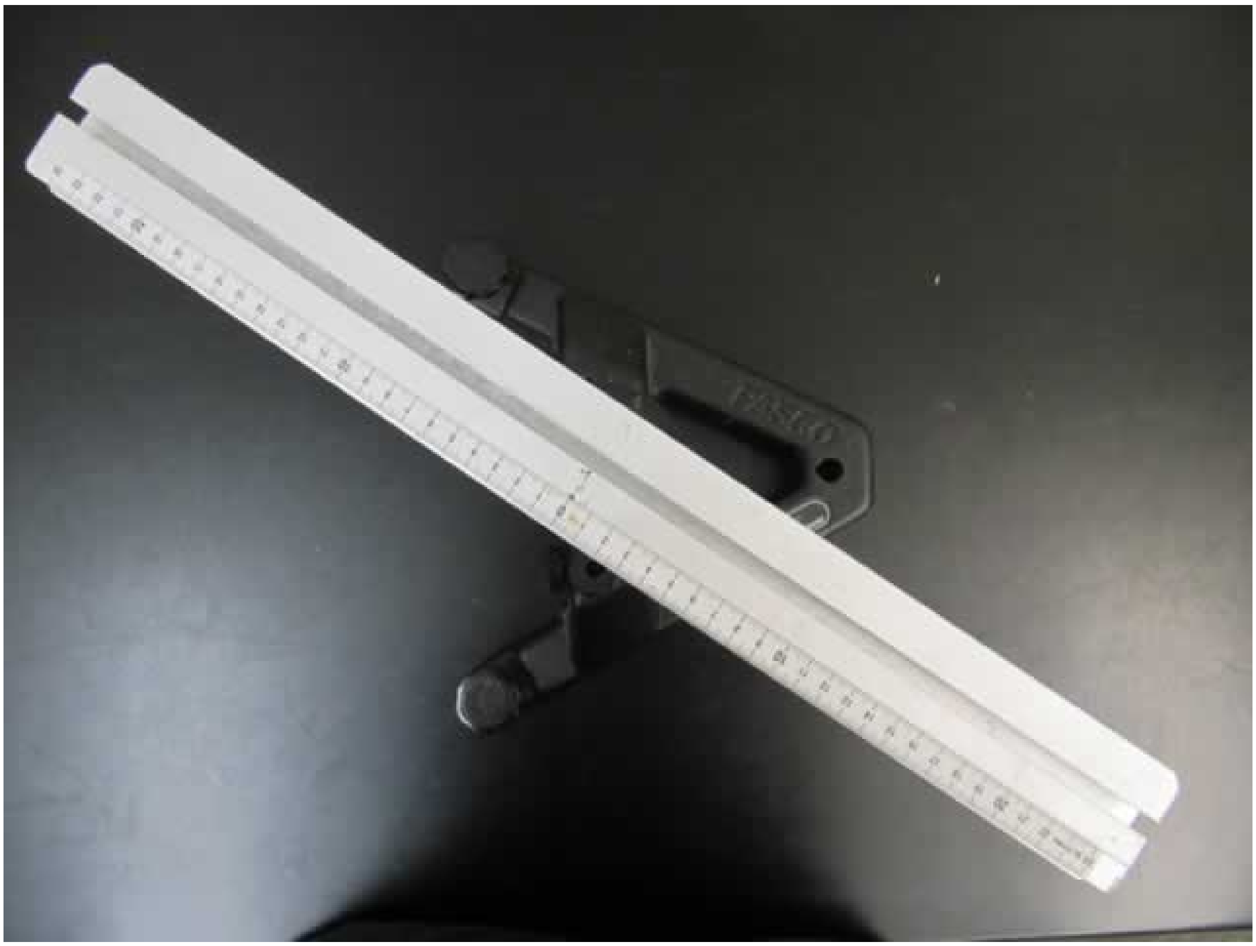
LAB 5, PROBLEM 1: ANGULAR AND LINEAR SPEED

PURPOSE

- To show the students that the linear speed of an object rotating at a constant angular speed is dependent on its distance from the axis of rotation.

EQUIPMENT

Rotating bar on base



TEACHING TIPS

- Have the students try spinning the beam at many different speeds. Make sure they take a movie of each trial to determine the range of speeds that will yield the best data.
- As you well know, the position and the angle of the camera will affect the accuracy of the data. Make sure that the camera is positioned directly over the center of the beam. Have your students try this at several different heights.
- Have your students find the best distance and angle such that the motion has the least amount of distortion. See Lab II Problem 5 of this guide for a picture of a good movie.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Even though this scenario should not be new to your students, most of them will still have difficulties dealing with it. The idea of tying linear motion into rotational motion is still new to them, so be careful of the analogies between the two. The students will most likely believe that there isn't a dependence between the linear speed and its distance from the axis of rotation since it is a solid, whole, object.

PREDICTION AND WARM-UP QUESTIONS

$v(r) = \omega r$,

$a(r) = \omega^2 r$,

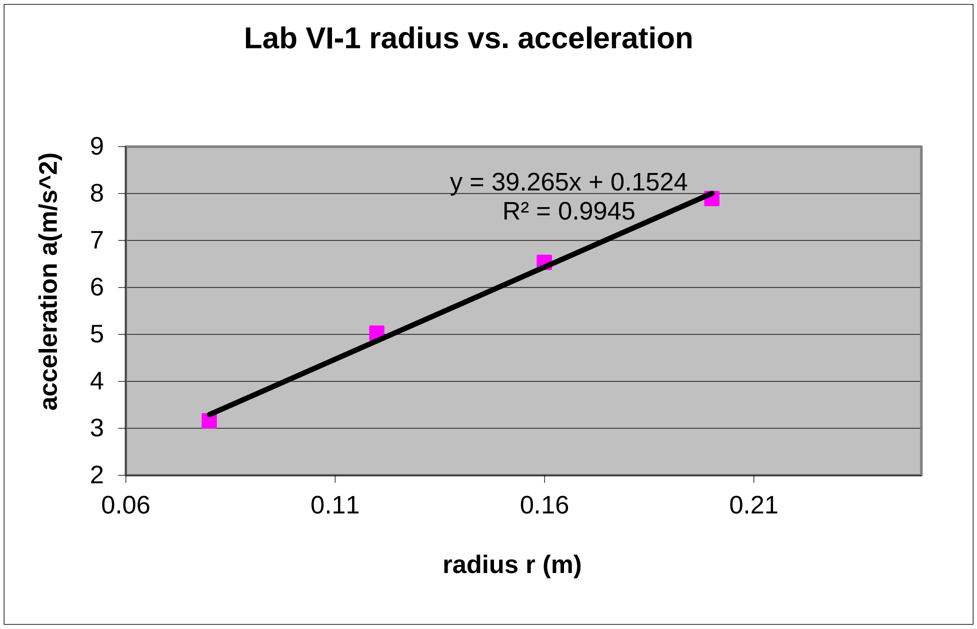
where r is the distance of the point from the axis of rotation, v is its linear speed, a is its acceleration and ω is its angular speed.

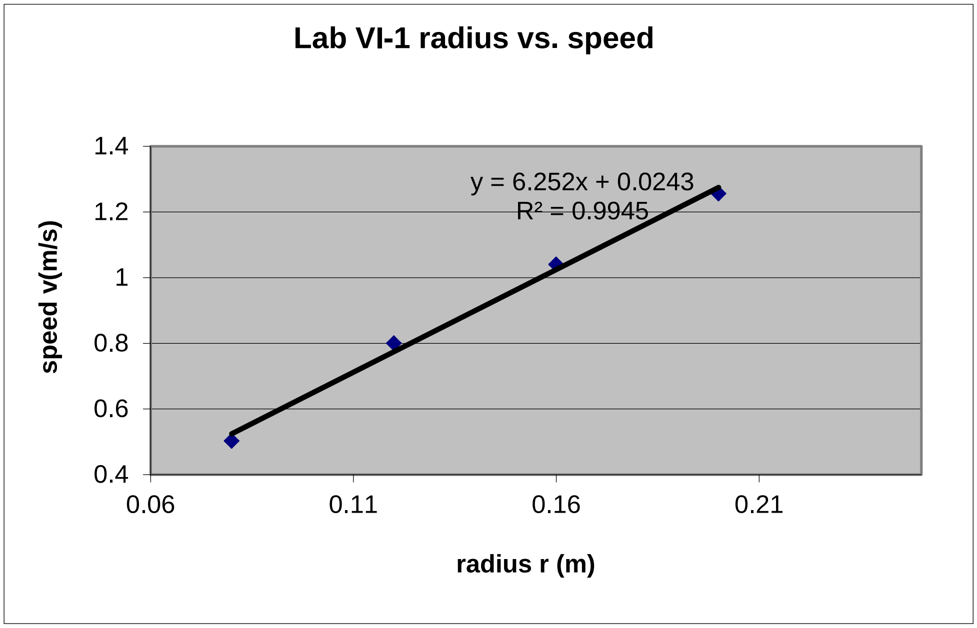
SAMPLE DATA

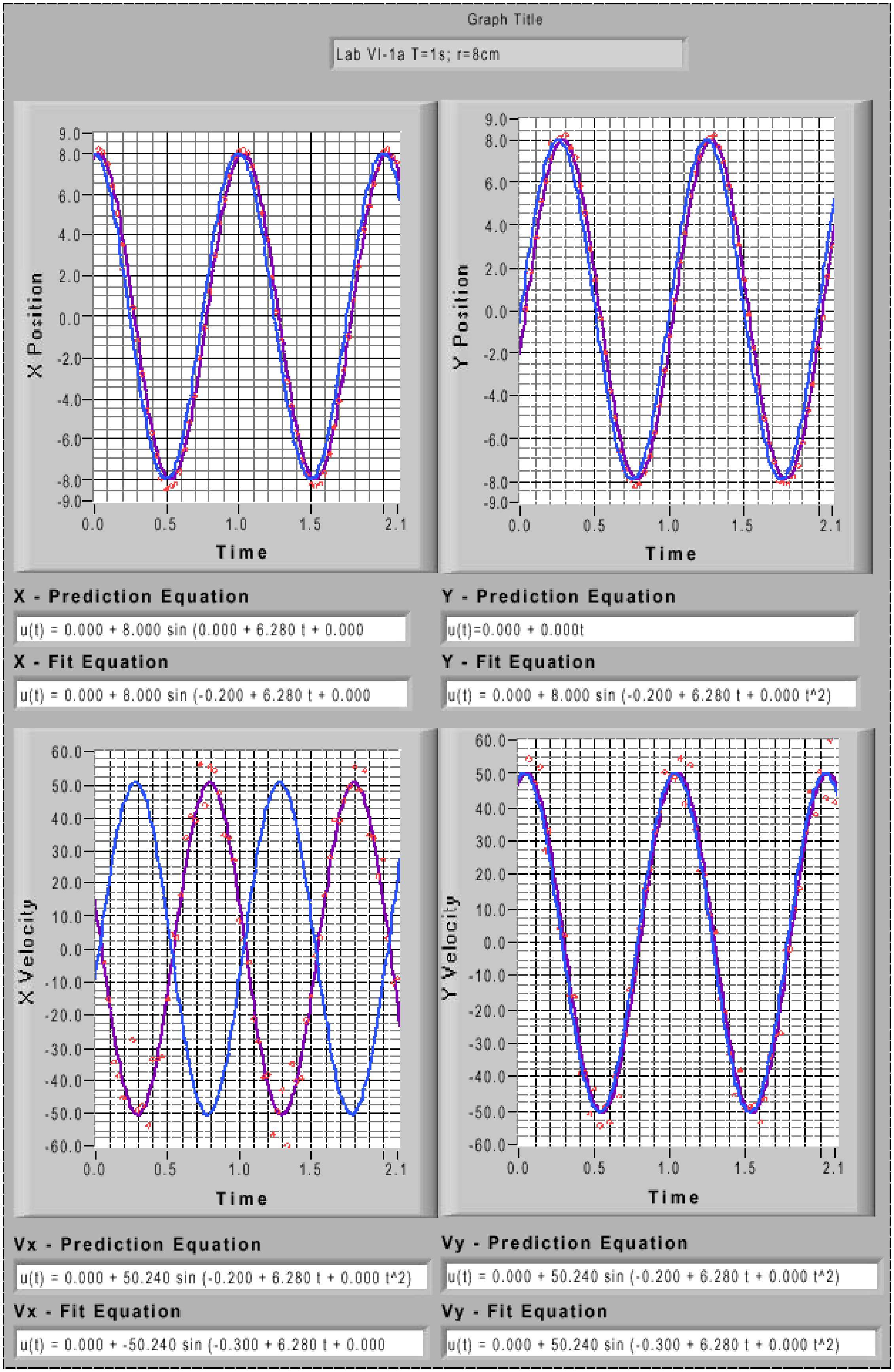
The printouts for the measurements of all velocities are included at the end of the following sample data.

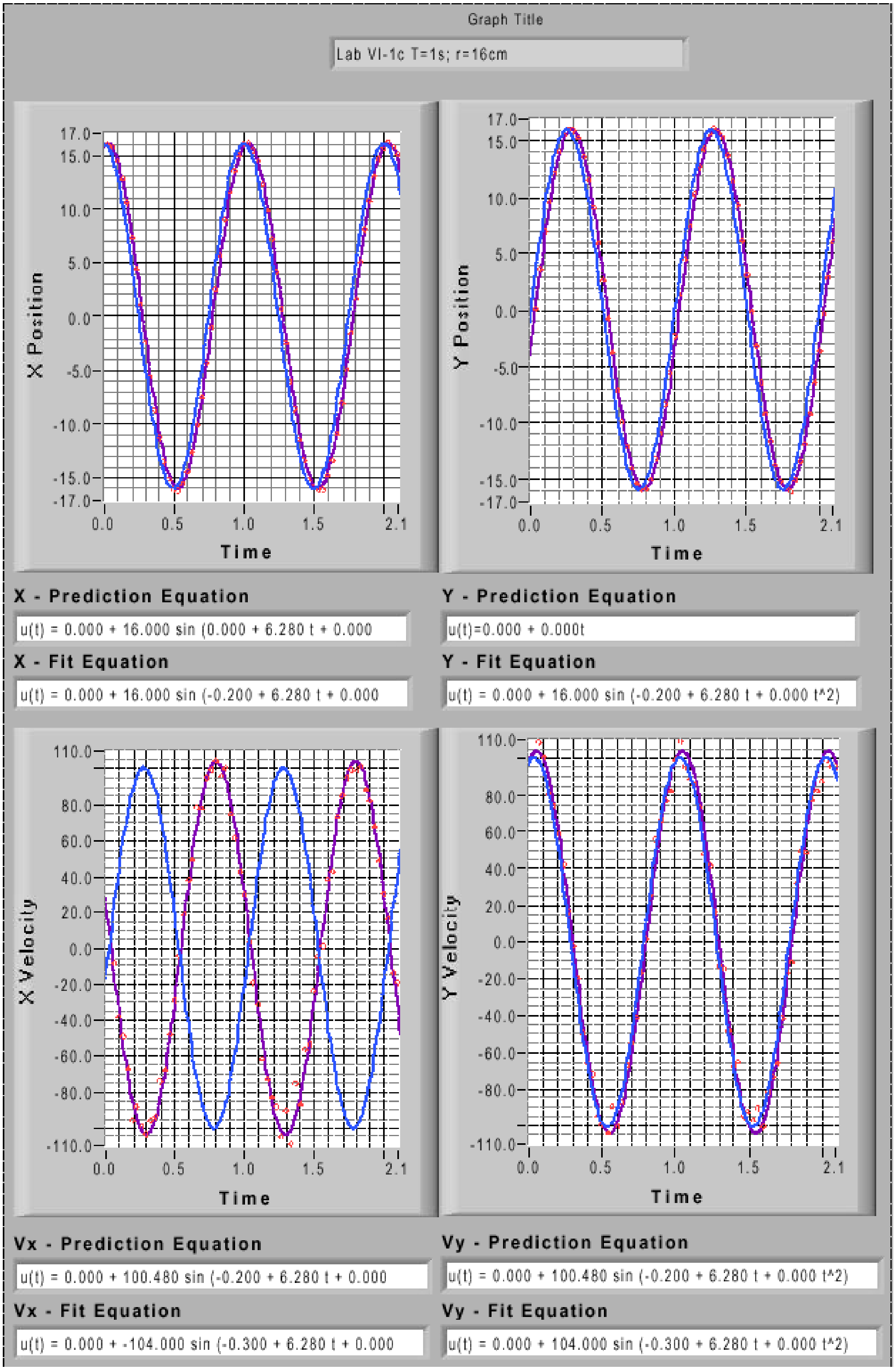
$\omega = 6.28$ s^{-1}

r (cm)	8	12	16	20
v (cm/s)	50.24	80	104	125.6
a (cm/s^2)	315.5	502.4	653.1	788.8


Lab VI-1 radius vs. acceleration
y = 39.265x + 0.1524
R² = 0.9945
acceleration a(m/s^2)
9
8
7
6
5
4
3
2
0.06
0.11
0.16
0.21
radius r (m)


Lab VI-1 radius vs. speed
y = 6.252x + 0.0243
R² = 0.9945
speed v(m/s)
1.4
1.2
1
0.8
0.6
0.4
0.06
0.11
0.16
0.21
radius r (m)


Graph Title
Lab VI-1a T=1s; r=8cm
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 8.000 sin (0.000 + 6.280 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 8.000 sin (-0.200 + 6.280 t + 0.000
Y - Fit Equation
u(t) = 0.000 + 8.000 sin (-0.200 + 6.280 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 50.240 sin (-0.200 + 6.280 t + 0.000 t^2)
Vy - Prediction Equation
u(t) = 0.000 + 50.240 sin (-0.200 + 6.280 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -50.240 sin (-0.300 + 6.280 t + 0.000
Vy - Fit Equation
u(t) = 0.000 + 50.240 sin (-0.300 + 6.280 t + 0.000 t^2)


Graph Title
Lab VI-1c T=1s; r=16cm
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 16.000 sin (0.000 + 6.280 t + 0.000
X - Fit Equation
u(t) = 0.000 + 16.000 sin (-0.200 + 6.280 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.000 + 16.000 sin (-0.200 + 6.280 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 100.480 sin (-0.200 + 6.280 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -104.000 sin (-0.300 + 6.280 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 100.480 sin (-0.200 + 6.280 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + 104.000 sin (-0.300 + 6.280 t + 0.000 t^2)

Lab 5, Problem 2: Rotation and Linear Motion at Constant Speed

Purpose

- To reproduce the relationship between a constant angular speed of an object and the linear speed causing it.

Equipment

Rotation base, spindle, spool, disk, ring, string, cart, track, meter stick, stopwatch

Teaching Tips

- Have the students try spinning the system at many different speeds. Make sure they take a movie of each trial to determine the range of speeds that will yield the best data.
- As you well know, the position and the angle of the camera will affect the accuracy of the data. Make sure that the camera is positioned directly over the center of the system. Have your students try this at several different heights.

- Have your students find the best distance and angle such that the motion has the least amount of distortion for both the linear part and the rotational part. See Lab 2 Problem 5 of this guide for an example of a "good movie."
- Make sure that the string does not slip at the ring.
- Make sure that the string is relatively taut throughout the entire motion capture, or at least during the time when the students will be taking data.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Even though this scenario should not be new to your students, most of them will still have difficulties dealing with it. The idea of tying linear motion into rotational motion is still new to them, so be careful of the analogies between the two. The students believe that a relationship exists, but may not know why it does.

PREDICTION AND WARM UP QUESTIONS

$$\omega = \frac{v}{r}$$

where ω is the angular speed of the disk, r is the radius of the ring, and v is the speed of the cart.

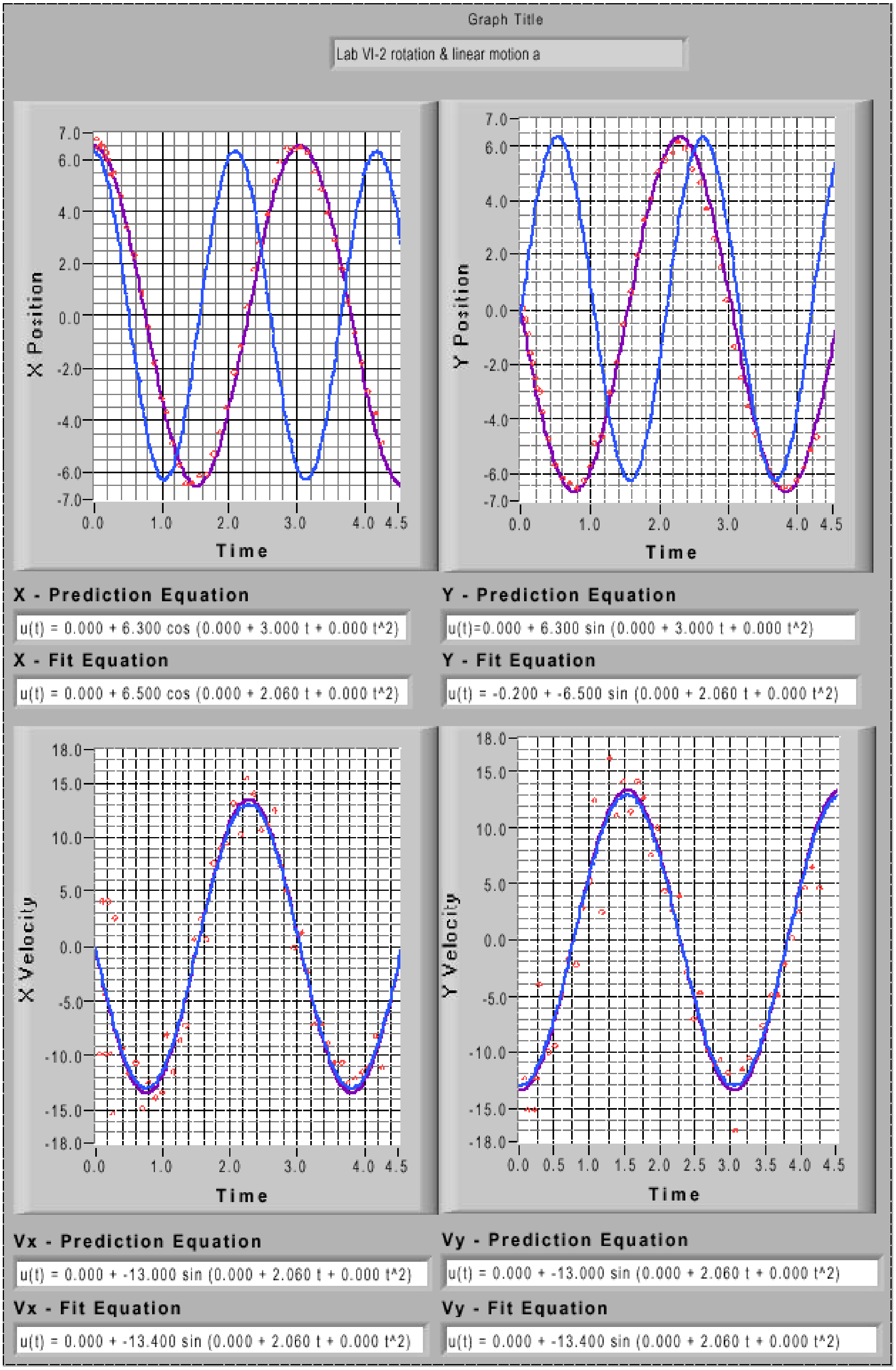
SAMPLE DATA

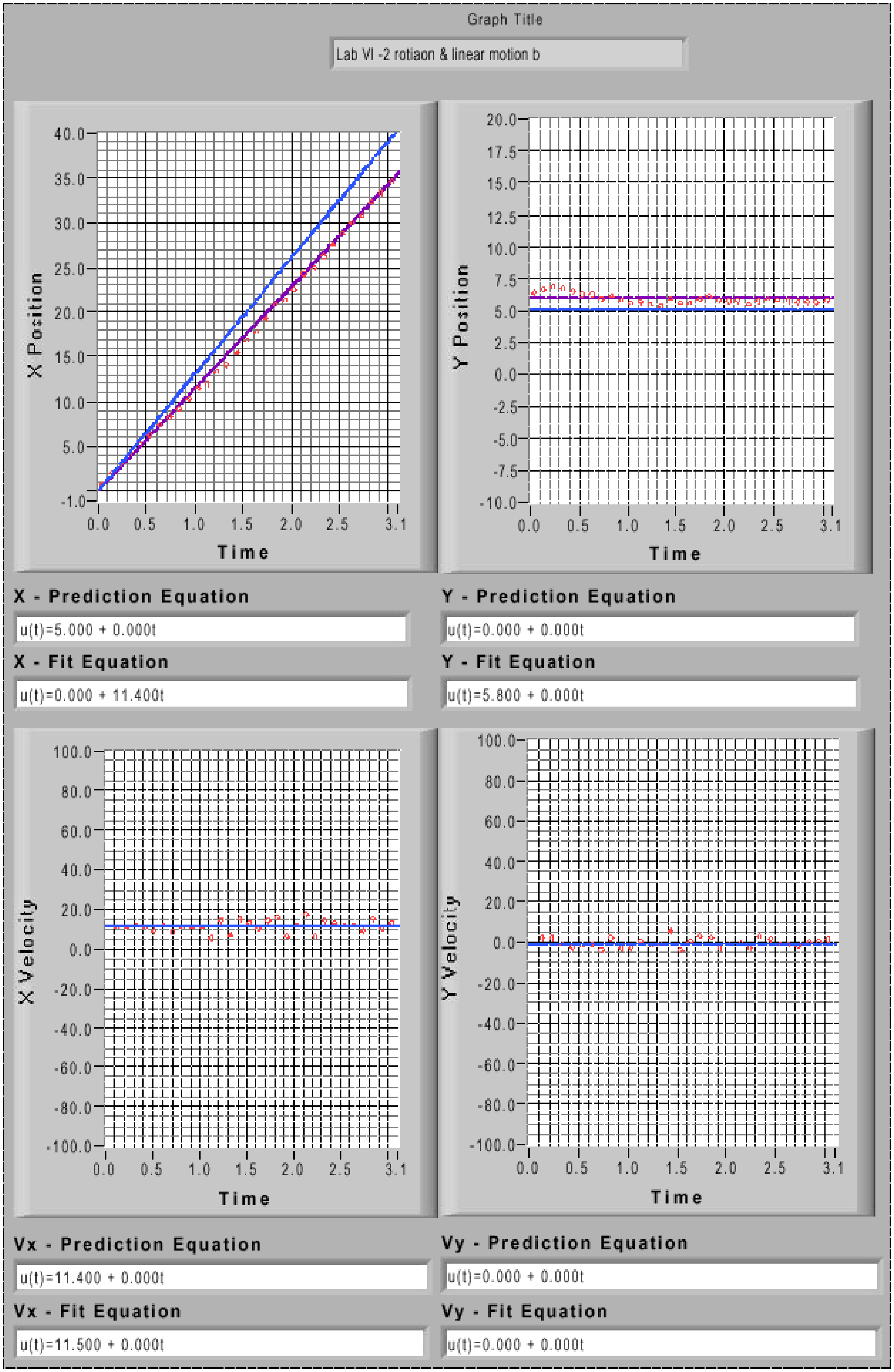
The printouts for the measurements of speed and angular speed are included at the end of the following sample data.

$r = 6.3$ (cm), $v = 11.5$ (cm/s),

predicted angular speed ω=1.825(s^{-1}),

measured angular speed $\omega = 2.06$ (s^{-1}).


Graph Title
Lab VI-2 rotation & linear motion a
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 6.300 cos (0.000 + 3.000 t + 0.000 t^2)
X - Fit Equation
u(t) = 0.000 + 6.500 cos (0.000 + 2.060 t + 0.000 t^2)
Y - Prediction Equation
u(t)=0.000 + 6.300 sin (0.000 + 3.000 t + 0.000 t^2)
Y - Fit Equation
u(t) = -0.200 + -6.500 sin (0.000 + 2.060 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -13.000 sin (0.000 + 2.060 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -13.400 sin (0.000 + 2.060 t + 0.000 t^2)
Vy - Prediction Equation
u(t) = 0.000 + -13.000 sin (0.000 + 2.060 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + -13.400 sin (0.000 + 2.060 t + 0.000 t^2)


Graph Title
Lab VI -2 rotiaon & linear motion b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=5.000 + 0.000t
X - Fit Equation
u(t)=0.000 + 11.400t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=5.800 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=11.400 + 0.000t
Vx - Fit Equation
u(t)=11.500 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

LAB 5, PROBLEM 3: ANGULAR AND LINEAR ACCELERATION

PURPOSE

To reproduce the relationship between the angular acceleration of an object and the linear acceleration that causes it.

EQUIPMENT

Rotation base, spindle, spool, disk, string, pulley, clamp, hanging mass set, meter stick, stopwatch

TEACHING TIPS

- Have the students try many different masses to produce different speeds. Make sure they take a movie of each trial to determine the range of masses that will yield the best data.

- As you well know, the position and the angle of the camera will affect the accuracy of the data. Make sure that the camera is positioned directly over the center of the disk. Have your students try this at several different heights.
- Have your students find the best distance and angle such that the motion has the least amount of distortion for both the linear part and the rotational part. See Lab 2 Problem 5 of this guide for an example of a "good movie."
- Make sure that the string does not slip at the spool.
- Make sure that the string is relatively taut throughout the entire motion capture, or at least during the time when the students will be taking data.
- Make sure that the students have the predictions as close to the correct answer as possible; they won't know what to look for or how to match the data otherwise.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Even though this scenario should not be new to your students, most of them will still have difficulties dealing with it. The idea of tying linear motion into rotational motion is still new to them, so be careful of the analogies between the two. The students believe that a relationship exists, but may not know why it does.

PREDICTION AND WARM-UP QUESTIONS

$$\alpha = \frac{a}{r}$$

Where α is the angular acceleration of the disk, a is the acceleration of the weight, and r is the radius of the spool.

$$x(t) = A + r\cos\theta(t),\ y(t) = B + r\sin\theta(t),$$

where the coordinates of the axis of rotation are (A,B), and the time dependence of θ for constant angular acceleration is given by $\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$.

Differentiating with respect to time:

$$v_x(t) = -r\theta'(t)\sin\theta(t),\ v_y(t) = r\theta'(t)\cos\theta(t)$$

Differentiating again with respect to time:

$$a_x(t) = -r\theta''(t)\sin\theta(t) - r(\theta'(t))^2\cos\theta(t),$$

$$a_y(t) = r\theta''(t)\cos\theta(t) - r(\theta'(t))^2\sin\theta(t)$$

Now, $a^2 = a_x^2 + a_y^2 \Rightarrow a(t)^2 = r^2(\theta''(t))^2 + r^2(\theta'(t))^4$

Using $\theta'(t) = \omega_0 + \alpha t$ and $\theta''(t) = \alpha$, we get:

$$a(t) = \sqrt{[r\alpha]^2 + \left[r(\omega_0 + \alpha t)^2\right]^2} \qquad \text{(A)}$$

Now, the centripetal acceleration is given by $a_C(t) = \omega(t)^2 r$, whereas the time dependence of the angular speed is given by $\omega(t) = \omega_0 + \alpha t$, so:

$$a_C(t) = r(\omega_0 + \alpha t)^2$$

The centripetal and tangential accelerations are perpendicular, and so:

$$a(t) = \sqrt{a_C(t)^2 + a_T(t)^2} = \sqrt{\left[r(\omega_0 + \alpha t)^2\right]^2 + a_T(t)^2} \qquad \text{(B)}$$

Comparing equations (A) and (B), the tangential acceleration is given by:

$$a_T(t) = r\alpha$$

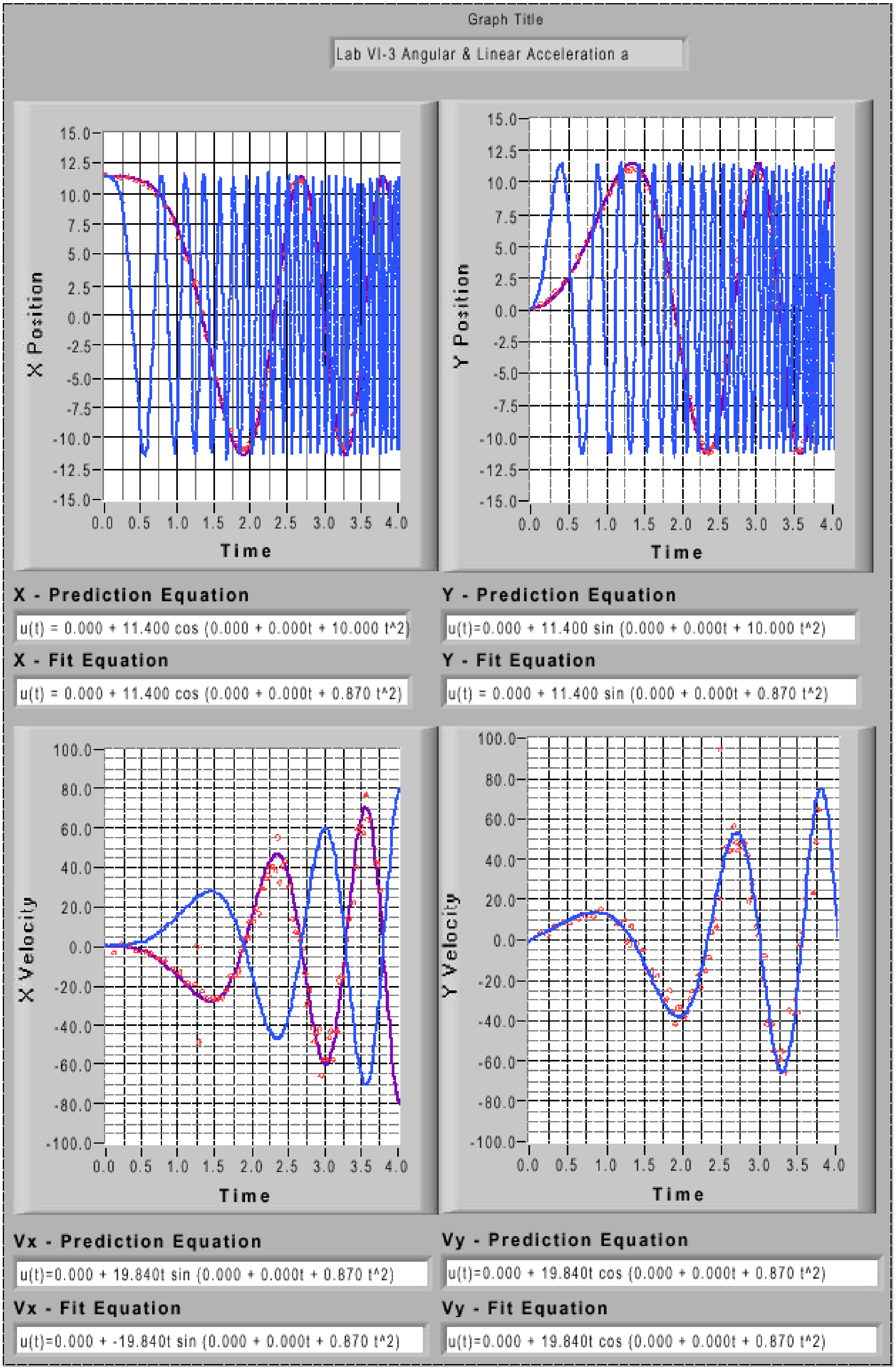
SAMPLE DATA

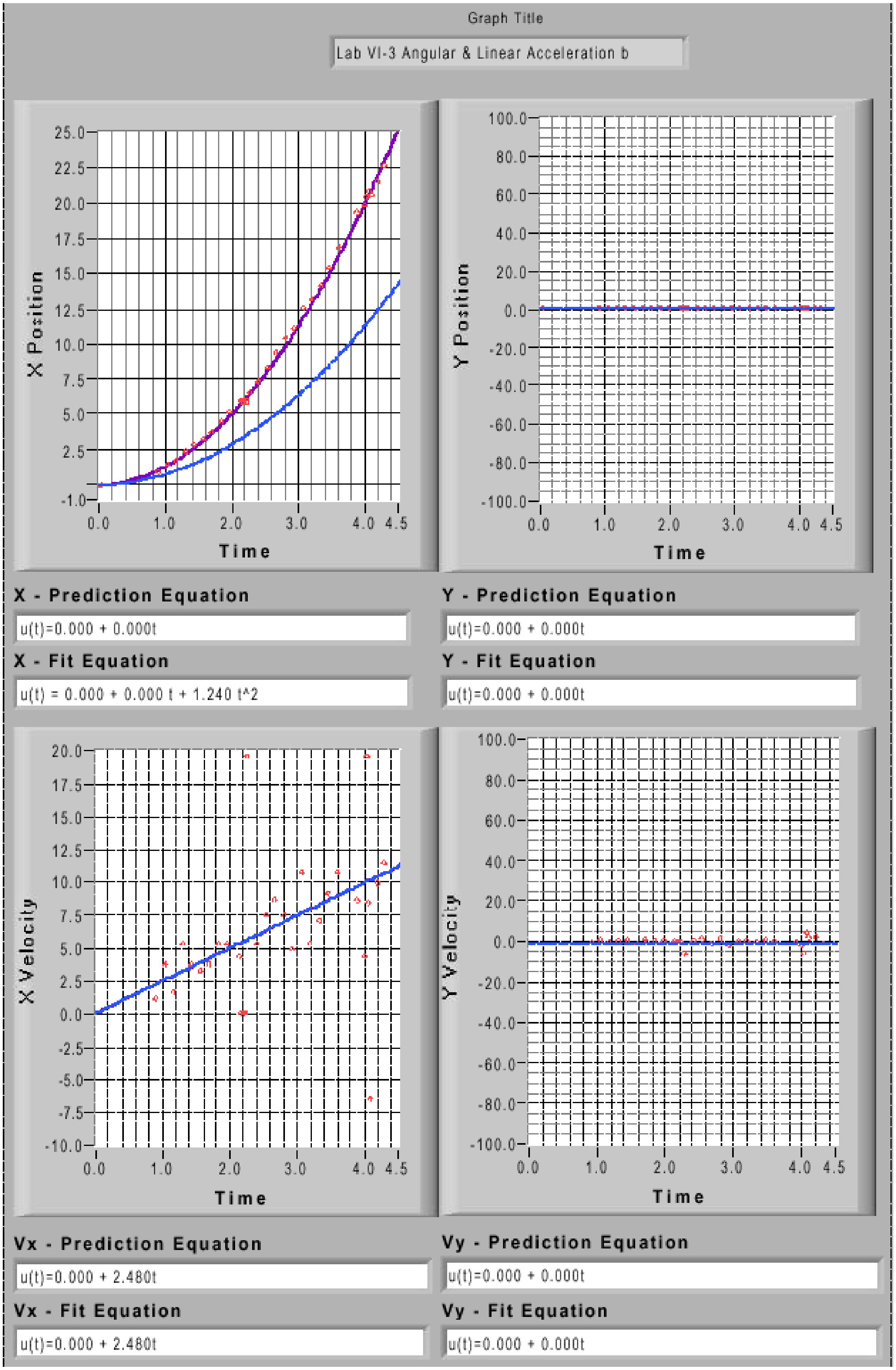
The printouts for the measurements of speed and angular speed are included at the end of the following sample data.

$r = 1.5$ (cm), $a = 2.48$ (cm/s^2),

predicted angular acceleration $\alpha = 1.65$ (s^{-2}),

measured angular acceleration $\alpha = 1.74$ (s^{-2}).


Graph Title
Lab VI-3 Angular & Linear Acceleration a
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 11.400 cos (0.000 + 0.000t + 10.000 t^2)
X - Fit Equation
u(t) = 0.000 + 11.400 cos (0.000 + 0.000t + 0.870 t^2)
Y - Prediction Equation
u(t)=0.000 + 11.400 sin (0.000 + 0.000t + 10.000 t^2)
Y - Fit Equation
u(t) = 0.000 + 11.400 sin (0.000 + 0.000t + 0.870 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 19.840t sin (0.000 + 0.000t + 0.870 t^2)
Vx - Fit Equation
u(t)=0.000 + -19.840t sin (0.000 + 0.000t + 0.870 t^2)
Vy - Prediction Equation
u(t)=0.000 + 19.840t cos (0.000 + 0.000t + 0.870 t^2)
Vy - Fit Equation
u(t)=0.000 + 19.840t cos (0.000 + 0.000t + 0.870 t^2)


Graph Title
Lab VI-3 Angular & Linear Acceleration b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 1.240 t^2
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 2.480t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t)=0.000 + 2.480t
Vy - Fit Equation
u(t)=0.000 + 0.000t

TA Lab Evaluations

Physics 1301 Lab 5: Rotational Kinematics

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to **labhelp@physics.umn.edu**, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

Do you have additional comments regarding student learning and these labs?

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

Lab Room

Was the room kept neat and clean by your class and other classes? (circle one) yes / no

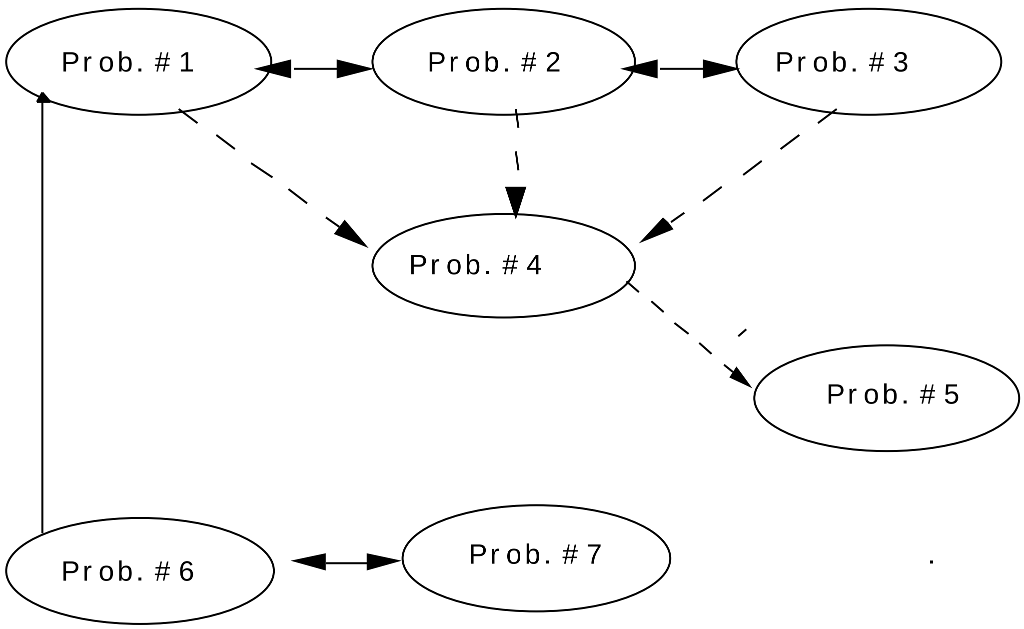
Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

LABORATORY 6: ROTATIONAL DYNAMICS

The purpose of this lab is to familiarize the students with the different quantities involved in rotational motion. As you probably know, the moment of inertia is a very elusive concept the first time around. It is good to discuss the different parameters that affect this. This lab also should help the students see some of the connections between torque, moment of inertia, and angular velocity.

By looking at the flow chart you can see that there are not any required problems in this lab. Also Problem #1, #2, and #3 are very similar – your students probably do not have to do all of these, unless they have run out of things to do.



GENERAL TEACHING TIPS

- The mass of the shaft and the mass of the spool are very difficult to remove, so feel free to give the students these values. The students should be able to determine the radii by themselves with careful measurement.

BY THE END OF THIS LAB, YOUR STUDENTS SHOULD BE ABLE TO

- Use the concept of torque in a system that is in static equilibrium.
- Relate the concepts of torque, angular acceleration, and rotational inertia for rigid bodies.
- Use the conservation principles of energy, momentum, and angular momentum for rigid body motion.

THINGS TO CHECK OUT BEFORE TEACHING THIS LAB

- It's fun to try out the mobile, but probably not necessary.
- It is very important to get a flat camera angle. The masses should fall in a plane perpendicular to the camera angle. Placing the setup on a stable chair on the table worked well, but it needs to be held down for Problem #3!
- Make sure you know how the spool set up works.
- It's good to try attaching some string and masses to the different setups to see what masses work.
- Too much mass will cause the string to break at the spool. Encourage students to increase the mass in reasonable amounts (about 100 g).
- Try **gently setting** the ring on the spinning disk for Problem #5. Conservation of momentum is always fun to play with.

LAB 6, PROBLEMS 1–3: MOMENT OF INERTIA

PURPOSE

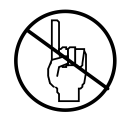
- **Problem 1:** To show the students that the rotational inertia of a complex system can be found by knowing the rotational inertia of the parts that make up the system.
- **Problem 2:** To determine how different axes of rotation of a system affect the moment of inertia.
- **Problem 3:** To determine how a circularly asymmetric distribution of mass affects the rotational inertia of the system.

EQUIPMENT

Rotation base, spindle, spool, disk, clamp, pulley, string, hanging mass set, stopwatch, meter stick

TEACHING TIPS

- These problems are very similar. They have similar predictions and warm up questions. Needless to say, the exploration, measurement, and analysis are also similar. It is unlikely that a group would do all three, unless your students are moving too quickly. You might consider dividing the class up and have groups who did the same problem report their average to the class. It will be useful to compare and contrast mass and rotational inertia.
- When the string needs to be attached to the spool, the hanging mass needs to be large to overcome the friction of the rod, to provide enough torque to spin the entire system, and to create an acceleration that the camera and analysis software can pick up. 1 kg worked well for Problems 1 and 2.
- When doing **Problem 3**, the system must be stable! **The ring must be fastened to the disk securely with tape** or it will fly off at great speed – especially if the students are using masses similar to the earlier problems. Use less mass – around 300 - 500 g. If the setup is on a chair, be sure the chair is held stable as well.



- The spool adds a small bit to the moment of inertia of the system, but it is negligible. If a group forgets about it, but argues convincingly about being able to forget it, you might let it pass. You may want to have them figure out what percent of the total it is, though.
- Be sure the students use the correct radius for the spool. Some students may be tempted to use the larger radius of the edges of the spool, but what is correct is to use the inner radius – where the string is actually wrapped.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Rotational inertia is a new concept to most students and they do not have an intuitive feel for magnitudes. They may not understand the importance of the axis of rotation and the distance from that axis.

PREDICTIONS AND WARM-UP QUESTIONS

PROBLEM 1

$$I_{TOT} = I_{ring} + I_{disk} + I_{shaft}$$

$$I_{TOT} = \tfrac{1}{2}M_R\left(R_0^2 + R_1^2\right) + \tfrac{1}{2}M_D R_D^2 + \tfrac{1}{2}M_S R_S^2$$

PROBLEM 2

$$I_{TOT} = I_{disk} + I_{shaft}$$

Axis through center: $I_{TOT} = \frac{1}{2}M_D R_D^2 + \frac{1}{2}M_S R_S^2$.

Axis through diameter: $I_{TOT} = \frac{1}{4}M_D R_D^2 + \frac{1}{12}M_D L^2 + \frac{1}{2}M_S R_S^2$.

Problem #3: $I_{TOT} = I_{ring} + I_{disk} + I_{shaft}$

$$I_{TOT} = \frac{1}{2}M_R\left(R_0^2 + R_1^2\right) + M_R d^2 + \frac{1}{2}M_D R_D^2 + \frac{1}{2}M_S R_S^2,$$

where M_R is the mass of the ring; M_D is the mass of the disk; M_S is the mass of the shaft$_0$ and R_1 are the inner and outer radii of the ring, respectively; R_D is the radius of the disk; L is the thickness of the disk; and R_S is the radius of the shaft. In the case of Problem #3, d is the distance between the center of the off-axis ring and the center of rotation.

PROBLEMS 1, 2, AND 3

The moment of inertia of the system can be calculated from the acceleration of the hanging weight, using the following expression:

$$I_{TOT} = \frac{R_S^2}{a} m(g - a),$$

where R_S is the radius of the spool, a is the linear acceleration, and m is the mass of the hanging weight.

SAMPLE DATA

The printouts for the measurements of all accelerations are included at the end of following sample data.

	Shaft	Disk	Ring	Spool
Mass (g)	222.5	1364.6	1431.1	-----
Radius (cm)	0.67	11.4	5.3/6.3	1.6

PROBLEM 1

Measured acceleration: $a = 1.82$ (cm/s^2),

Mass of hanging object: $m = 100$ (g),

Momentum of Inertia from sum: I_{TOT}=1.372e-2(kg*m^2),

Momentum of Inertia from acceleration: I_{TOT}=1.376e-2(kg*m^2).

PROBLEM 2

- axis through center
  Measured acceleration: $a = 2.48$ (cm/s^2),
  Mass of hanging object: $m = 100$ (g),
  Momentum of Inertia from sum: I_{TOT} = 8.87e-3 (kg*m^2),
  Momentum of Inertia from acceleration: I_{TOT}=1.01e-2 (kg*m^2).
- axis through diameter
  Measured acceleration: $a = 5.56$ (cm/s^2),
  Mass of hanging object: $m = 100$ (g),
  Momentum of Inertia from sum: I_{TOT} = 4.51e-3 (kg*m^2),
  Momentum of Inertia from acceleration: I_{TOT} = 4.49e-3 (kg*m^2).

PROBLEM 3

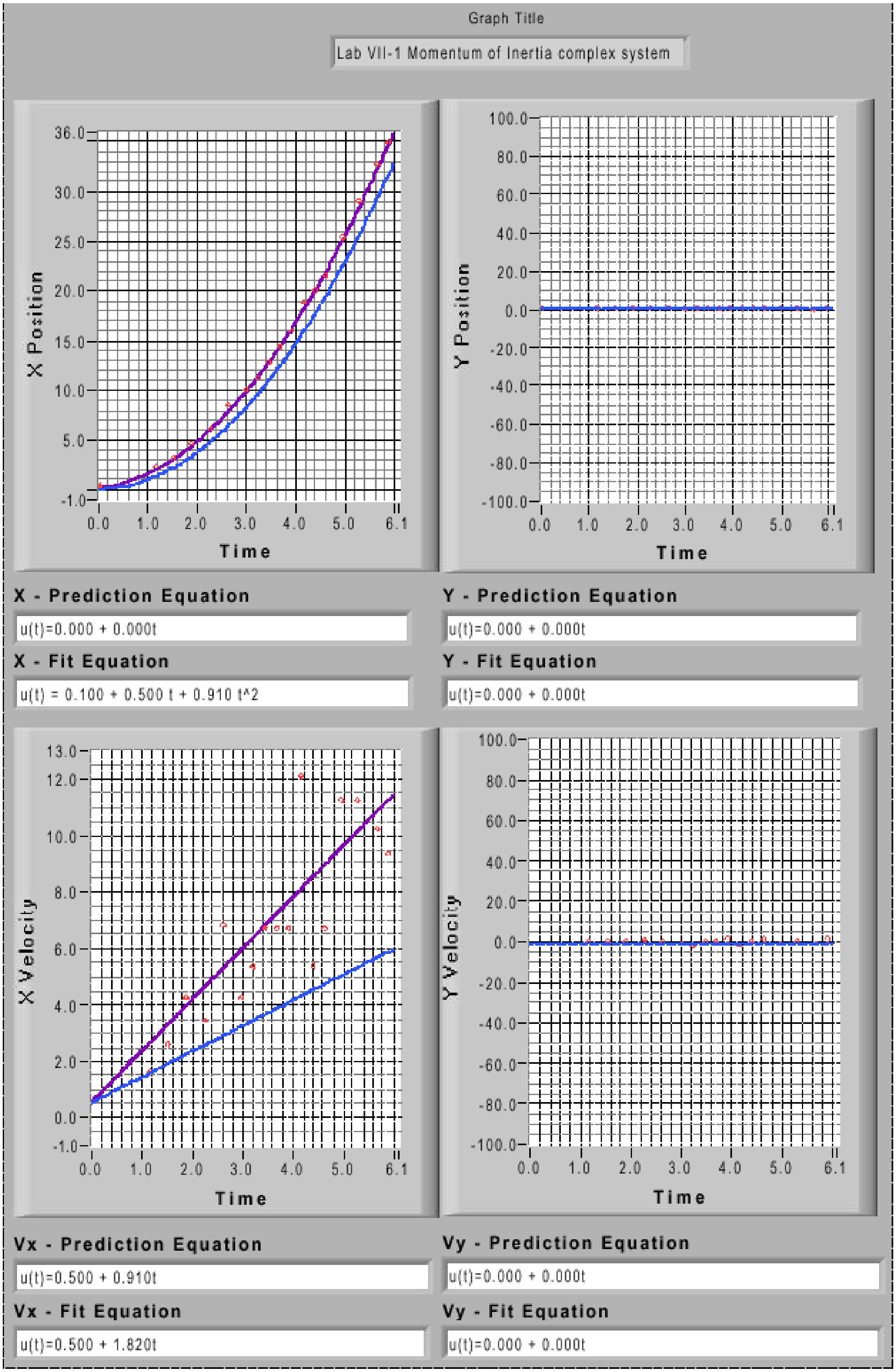
Measured acceleration: $a = 1.48$ (cm/s^2),

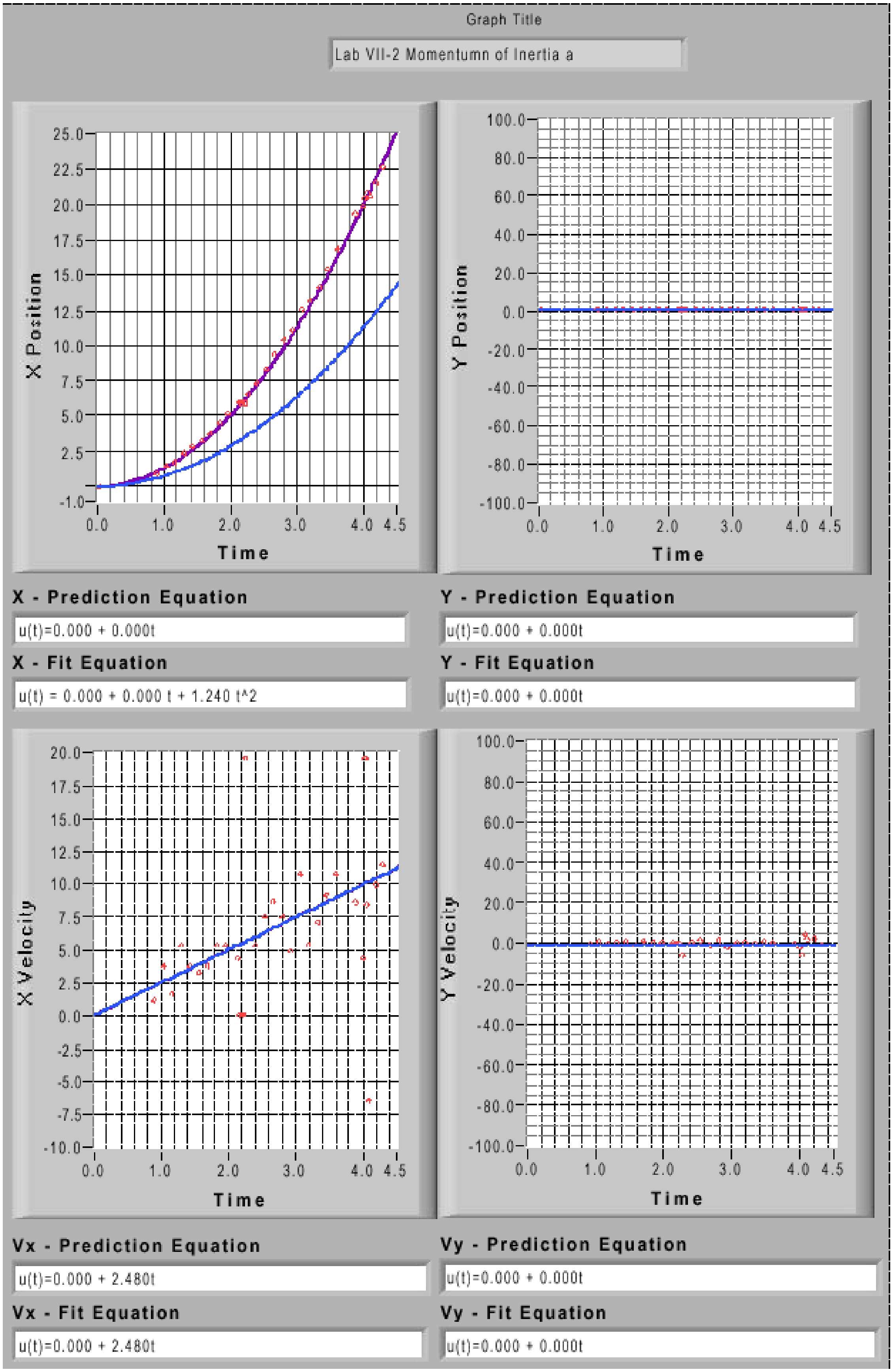
Mass of hanging object: $m = 100$ (g),

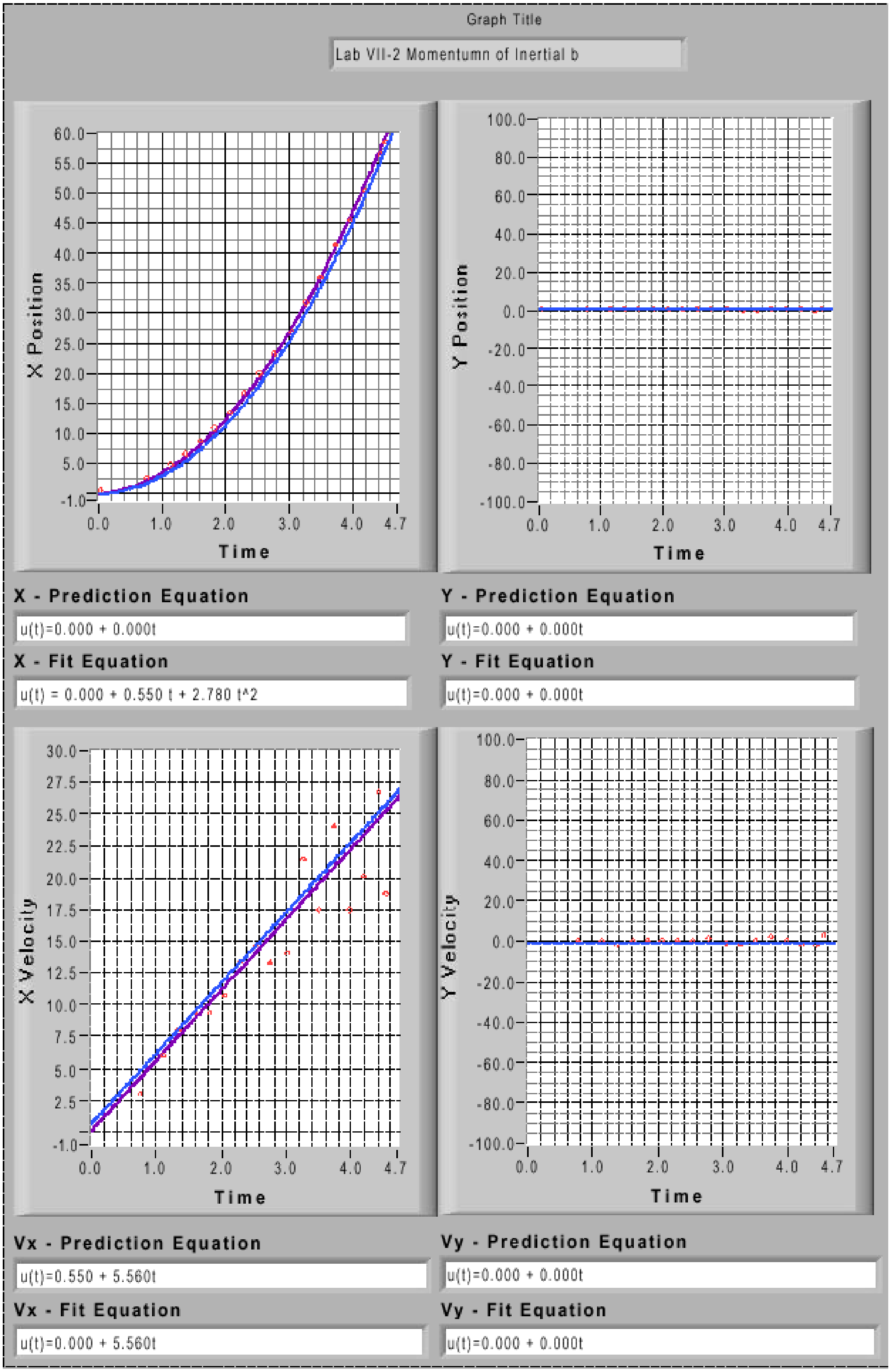
Distance between center of disk and center of ring: $d = 4.8$ (cm),

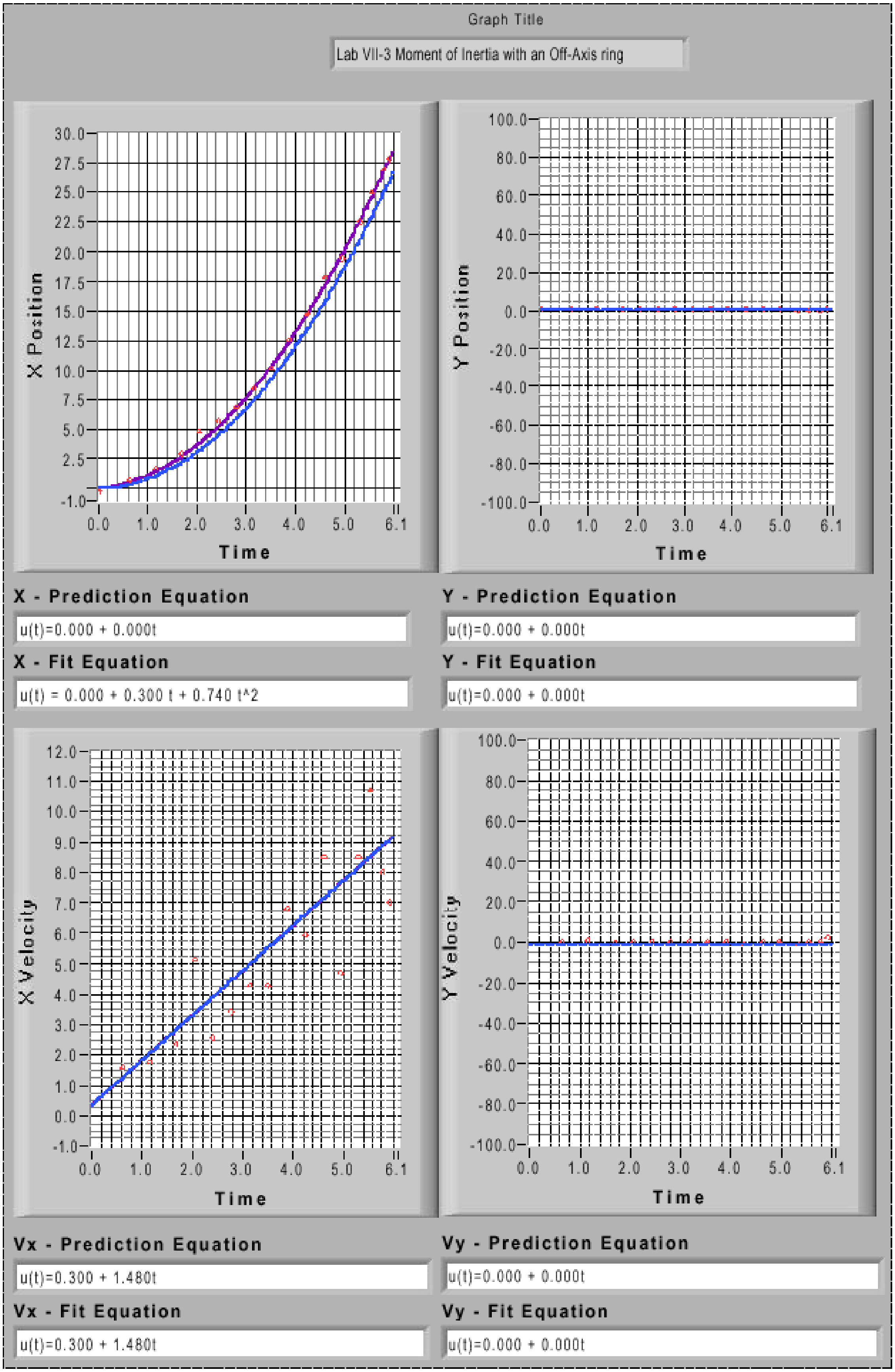
Momentum of Inertia from sum: I_{TOT} = 1.702e-2 (kg*m^2),

Momentum of Inertia from acceleration: I_{TOT} = 1.696e-2 (kg*m^2).


Graph Title
Lab VII-1 Momentum of Inertia complex system
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.100 + 0.500 t + 0.910 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.500 + 0.910t
Vx - Fit Equation
u(t)=0.500 + 1.820t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VII-2 Momentumn of Inertia a
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 1.240 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 2.480t
Vx - Fit Equation
u(t)=0.000 + 2.480t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VII-2 Momentumn of Inertial b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.550 t + 2.780 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.550 + 5.560t
Vx - Fit Equation
u(t)=0.000 + 5.560t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VII-3 Moment of Inertia with an Off-Axis ring
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.300 t + 0.740 t^2
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.300 + 1.480t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t)=0.300 + 1.480t
Vy - Fit Equation
u(t)=0.000 + 0.000t

LAB 6, PROBLEM 4: FORCES, TORQUE, AND ENERGY

PURPOSE

- To determine which placement of the force will create the greatest angular velocity with the same hanging object

EQUIPMENT

Rotation base, spindle, spool, disk, string, pulley, clamp, hanging mass set, meter stick, stopwatch

TEACHING TIPS

- The mass is a bit tricky for this problem, since a mass that works for the spool might not work when attached to the disk. 300 g gave reasonable, though sometimes small, accelerations that the analysis program could pick up. It also kept the velocities safe for all three setups.

- The distance, h, that the suspended mass falls is one of the experimental controls and must be kept the same for each trial. This is complicated by the different pulleys. If the students measure from the pulleys, *h* may be different for each run. It should be measured from the floor, and different amounts of string may be necessary.
- The mass should hit before the string completely unwraps. This will also ensure that *h* is the same for all trials.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Most students are not yet comfortable with energy conservation. This is a problem that uses rotational kinetic energy, gravitational potential energy, and linear kinetic energy. Students may also have difficulty relating angular acceleration of the disk and the linear acceleration of the suspended mass. This is really a problem in understanding rotational coordinates.

PREDICTION AND WARM-UP QUESTIONS

$$\omega = \sqrt{\frac{2mgh}{mr^2 + I}},$$

where m is the mass of the hanging weight, h is the height through which the weight falls, I is the moment of inertia of the whole rotating system about the center of rotation, and r is the radius of the object the string is wrapped around.

The shaft gives the largest ω since it has the smallest r.

Tension of string: $T = \frac{I}{I + mr^2} mg$.

SAMPLE DATA

The printouts for the measurements of all final angular speeds are included at the end of following sample data.

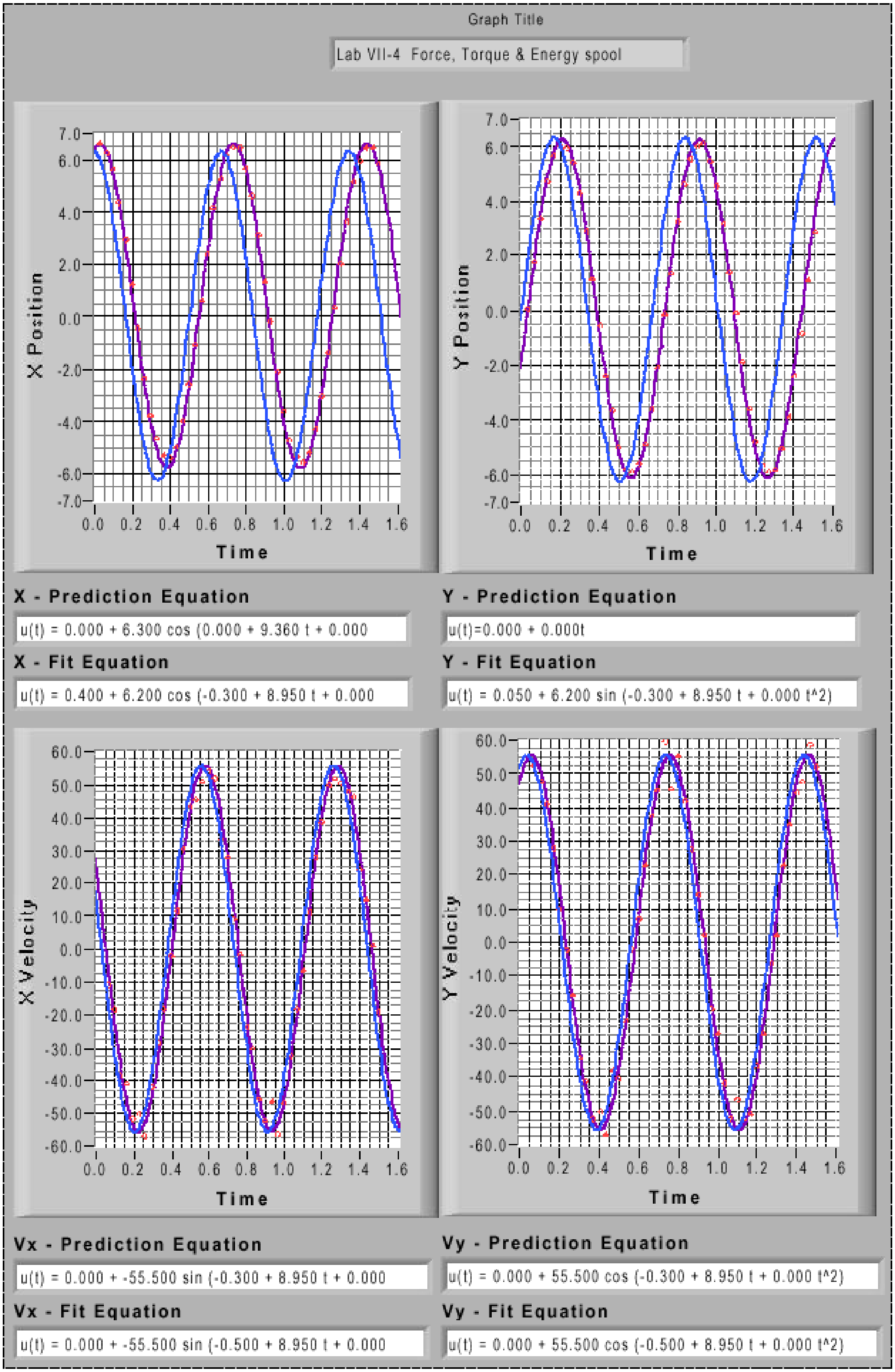
	Shaft	Disk	Ring	Spool
Mass (g)	222.5	1364.6	1431.1	-----
Radius (cm)	0.67	11.4	5.3/6.3	1.6

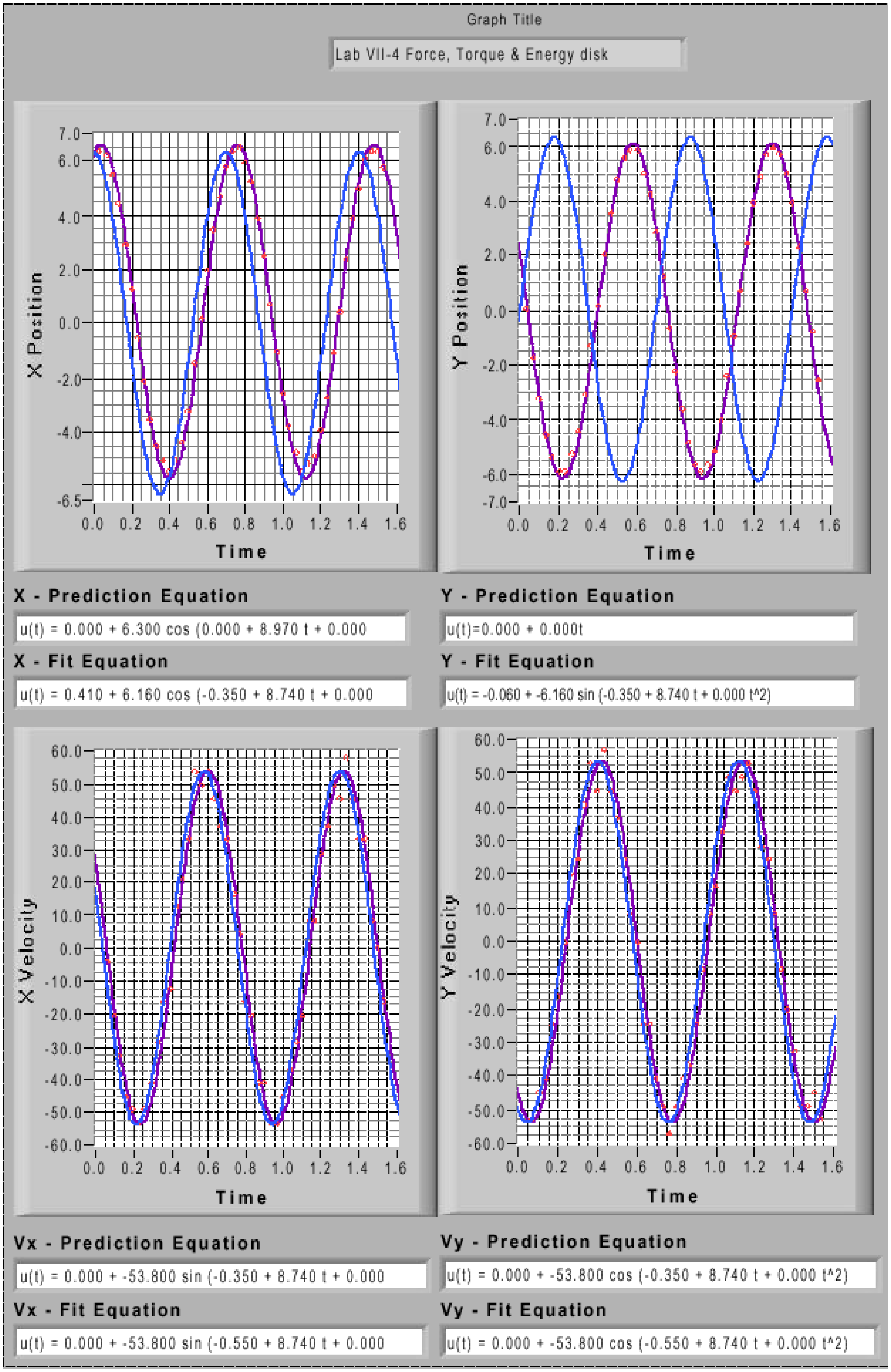
I=1.372e-2(kg*m^2),

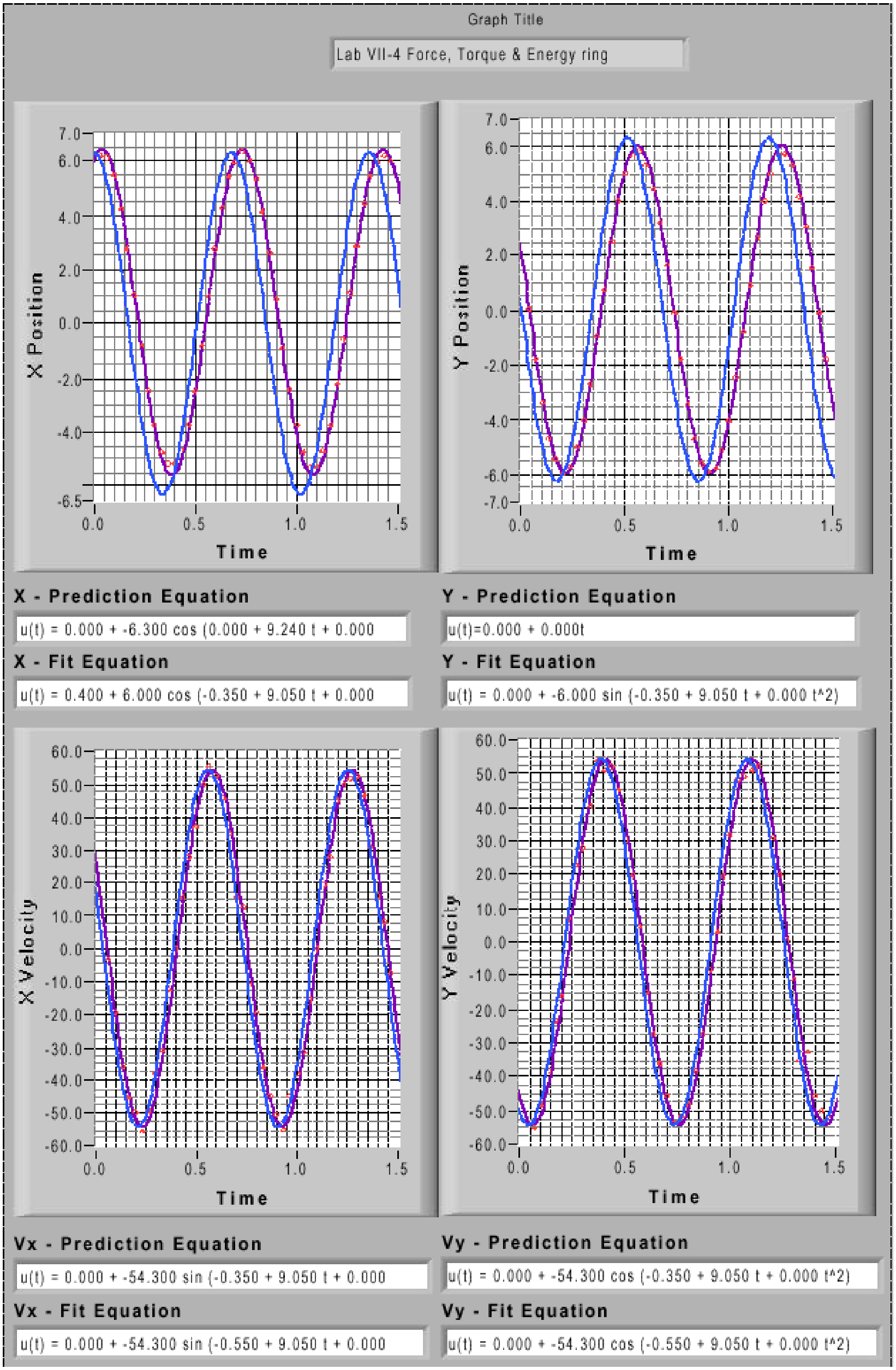
$m = 100$ (g),

$h = 61.5\,(\text{cm})$,

Position for wrapping string	Spool	Ring	Disk
Predicted angular speed ω (s^{-1})	9.36	9.24	8.96
Measured angular speed ω (s^{-1})	8.95	9.05	8.74


Graph Title
Lab VII-4 Force, Torque & Energy spool
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 6.300 cos (0.000 + 9.360 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.400 + 6.200 cos (-0.300 + 8.950 t + 0.000
Y - Fit Equation
u(t) = 0.050 + 6.200 sin (-0.300 + 8.950 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -55.500 sin (-0.300 + 8.950 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 55.500 cos (-0.300 + 8.950 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -55.500 sin (-0.500 + 8.950 t + 0.000
Vy - Fit Equation
u(t) = 0.000 + 55.500 cos (-0.500 + 8.950 t + 0.000 t^2)


Graph Title
Lab VII-4 Force, Torque & Energy disk
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 6.300 cos (0.000 + 8.970 t + 0.000
X - Fit Equation
u(t) = 0.410 + 6.160 cos (-0.350 + 8.740 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = -0.060 + -6.160 sin (-0.350 + 8.740 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -53.800 sin (-0.350 + 8.740 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -53.800 sin (-0.550 + 8.740 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + -53.800 cos (-0.350 + 8.740 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + -53.800 cos (-0.550 + 8.740 t + 0.000 t^2)


Graph Title
Lab VII-4 Force, Torque & Energy ring
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + -6.300 cos (0.000 + 9.240 t + 0.000
X - Fit Equation
u(t) = 0.400 + 6.000 cos (-0.350 + 9.050 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.000 + -6.000 sin (-0.350 + 9.050 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -54.300 sin (-0.350 + 9.050 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -54.300 sin (-0.550 + 9.050 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + -54.300 cos (-0.350 + 9.050 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + -54.300 cos (-0.550 + 9.050 t + 0.000 t^2)

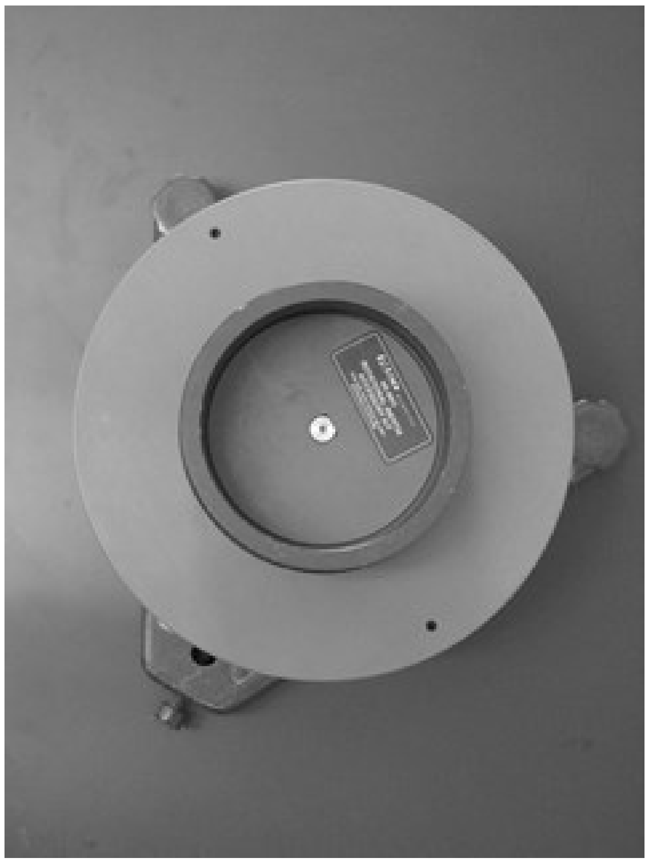
LAB 6, PROBLEM 5: CONSERVATION OF ANGULAR MOMENTUM

PURPOSE

- To demonstrate the concept of conservation of angular momentum by measuring the angular velocity before and after an inelastic collision.

EQUIPMENT

Rotation base, spindle, disk, ring



TEACHING TIPS

- The consistency of the timekeeper is the largest source of error in this problem. Tell your students to have everyone try for consistent times by turning the timer on and off as quickly as possible. The most consistent person should time. Estimate their error by this test.
- The timing error comes in twice; once to start the watch and again to stop it.
- The disk should be rotating quickly enough so that the students can barely time it.

- I found it useful to put a small piece of tape on the disk as a reference point. Be sure your students remove it when they leave the room.
- The students should drop the ring **gently**.
- Have the students perform multiple runs.
- A good question to ask is for other ways that one can change angular velocity using conservation of angular momentum. The canonical example is that of a figure skater extending her arms as she spins.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

This is an on-axis rotational inelastic collision. Students may still have difficulty with collisions and rotational coordinates, especially concerning the direction of the angular momentum.

PREDICTION AND WARM-UP QUESTIONS

$$\omega' = \frac{(I_{Disk} + I_{Shaft})}{(I_{Disk} + I_{Shaft} + I_{Ring})}\omega,$$

where ω is the initial angular velocity of the system, and ω' is the final angular velocity of the system.

SAMPLE DATA

The printouts for the measurements of all final angular speeds are included at the end of following sample data.

	Shaft	Disk	Ring	Spool
Mass (g)	222.5	1364.6	1431.1	-----
Radius (cm)	0.67	11.4	5.3/6.3	1.6

$I_{Disk} = 8.867$ e-3(kg*m^2),

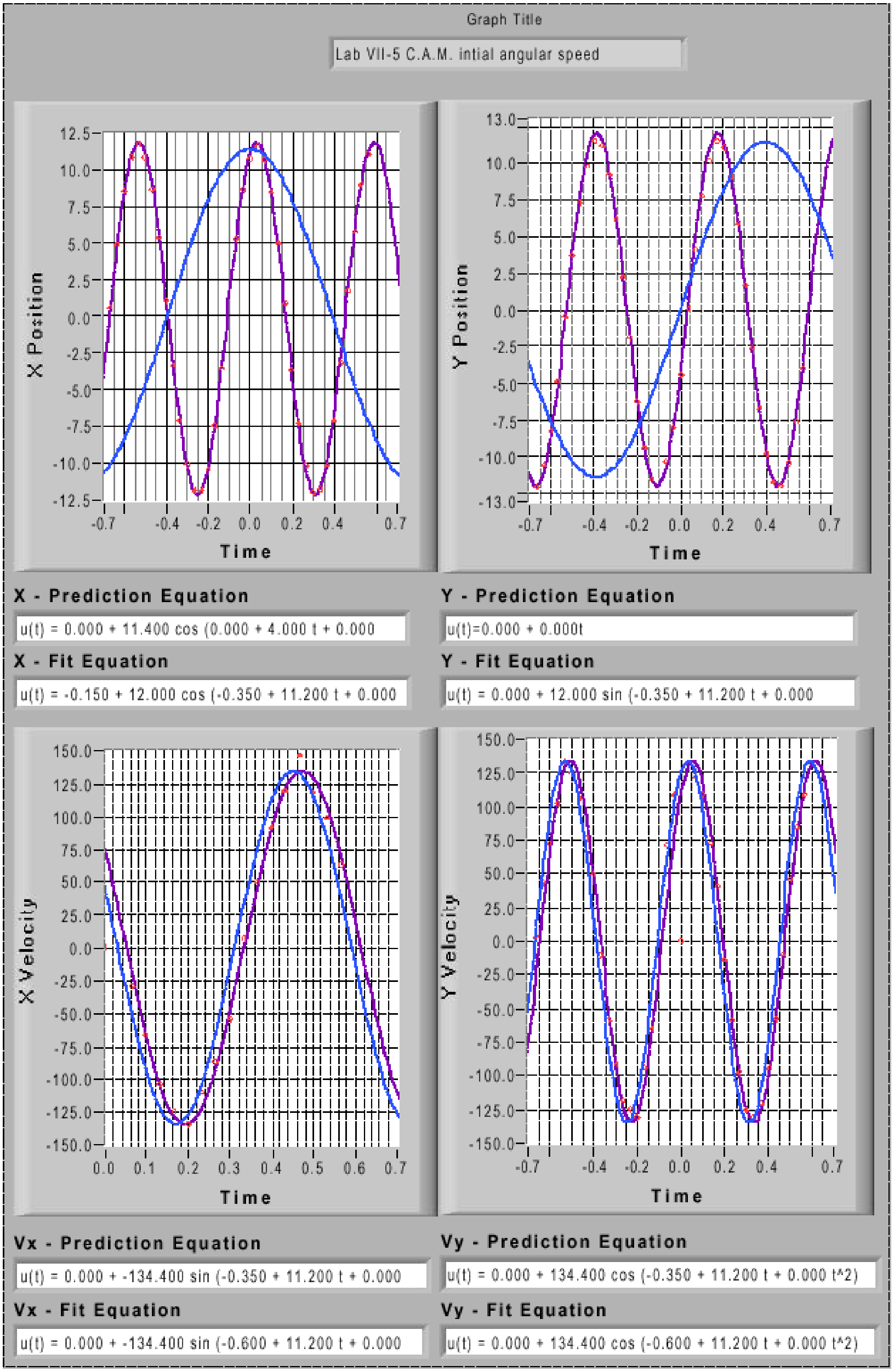
$I_{Ring} = 4.85$ e-3(kg*m^2),

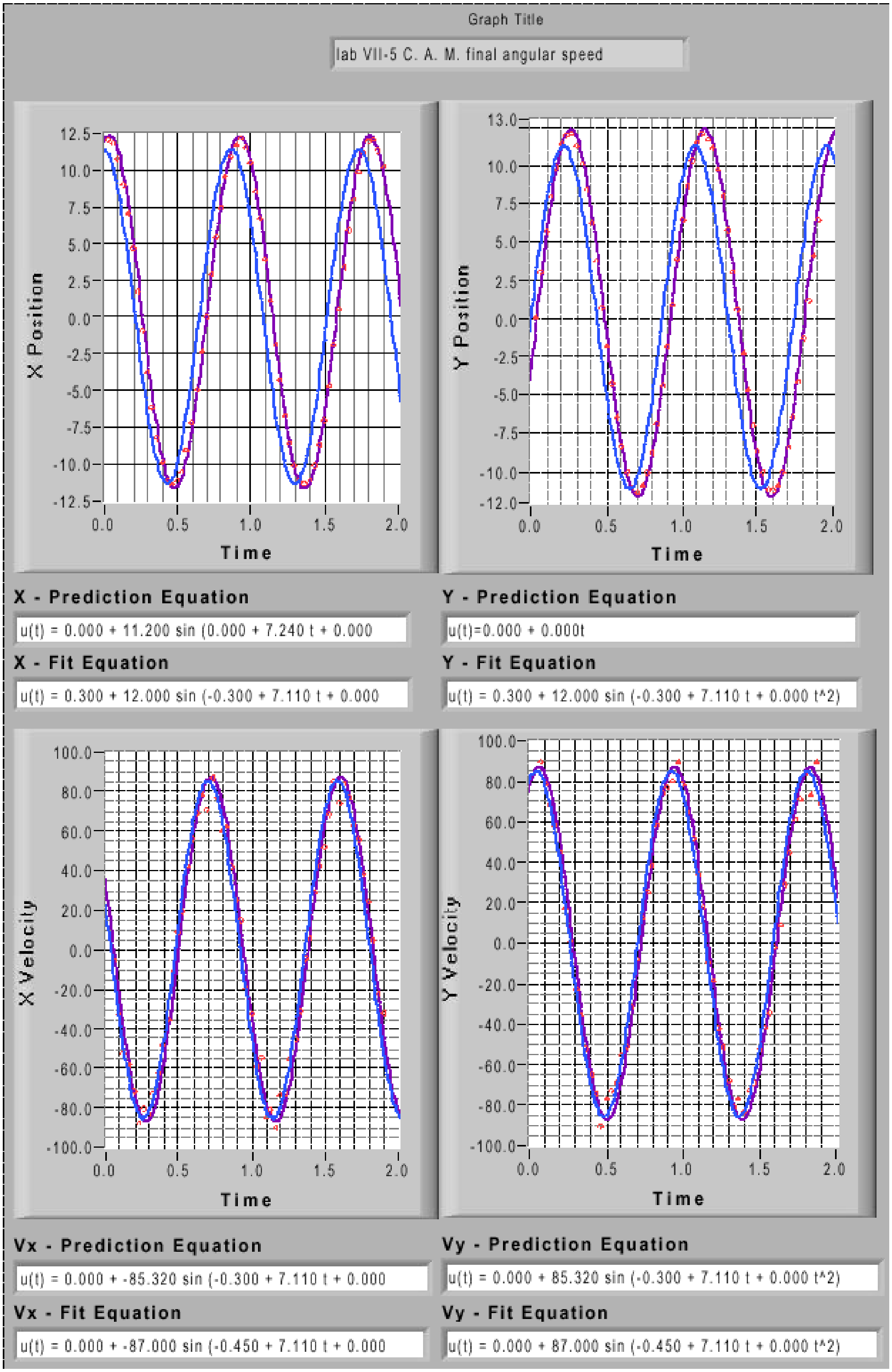
$I_{Shaft} = 4.994$ e-6(kg*m^2),

Initial angular speed $\omega_i = 11.2$ (s^{-1}),

Predicted final angular speed $\omega_f = 7.24$(s^{-1}),

Measured final angular speed $\omega_f = 7.11$(s^{-1}).


Graph Title
Lab VII-5 C.A.M. intial angular speed
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 11.400 cos (0.000 + 4.000 t + 0.000
X - Fit Equation
u(t) = -0.150 + 12.000 cos (-0.350 + 11.200 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.000 + 12.000 sin (-0.350 + 11.200 t + 0.000
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -134.400 sin (-0.350 + 11.200 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -134.400 sin (-0.600 + 11.200 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 134.400 cos (-0.350 + 11.200 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + 134.400 cos (-0.600 + 11.200 t + 0.000 t^2)


Graph Title
lab VII-5 C. A. M. final angular speed
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 11.200 sin (0.000 + 7.240 t + 0.000
X - Fit Equation
u(t) = 0.300 + 12.000 sin (-0.300 + 7.110 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.300 + 12.000 sin (-0.300 + 7.110 t + 0.000 t^2)
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -85.320 sin (-0.300 + 7.110 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -87.000 sin (-0.450 + 7.110 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 85.320 sin (-0.300 + 7.110 t + 0.000 t^2)
Vy - Fit Equation
u(t) = 0.000 + 87.000 sin (-0.450 + 7.110 t + 0.000 t^2)

LAB 6, PROBLEM 6: DESIGNING A MOBILE

PURPOSE

- To present the idea of balancing torque and forces in a familiar setting.

EQUIPMENT

Clamp, wooden dowels, hanging mass sets, string

TEACHING TIPS

- The wooden dowel rods do not have a uniform mass density, so the students are asked to find the center of mass of each rod. When you assign the problem, you should point this out to your students!
- Building a mobile might be common sense for some people. To discourage them from building the mobile first and then predicting the results, you should keep the masses until you are satisfied that they have completed the prediction.

- You will need to decide which masses to give to each group. Mix it up. Do not use masses larger than 50g, but feel free to bundle some masses together (i.e. a 20g mass and a 10g mass together). Have your students use unequal masses for the lower dowel. They already know that equal masses will balance with the string at the center of mass of the rod.
- If the students mark the dowel rods for the string placements, ask them to erase the marks when they are done. Don't encourage the students to make marks, but don't discourage it either. We are using wood dowel rods because they are cheap, reusable in the next lab, and erasable. You should have extra dowel rods on the prep table, so replace the rods when they are no longer usable.
- The prediction equations are messy, but every term is identifiable and the mobile won't balance if they leave out a term (or use the center of the rod for the center of mass!), so expect good results. Note that the torque equations for the two rods are similar, but the final equations should be expressed in terms that the students can measure in the lab (e.g., mass and length).

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Torque is mystical to most students. Beware of students simply summing up all the torque without taking the direction of rotation into consideration.

PREDICTION AND WARM-UP QUESTIONS

$$r_1 = \frac{l_1(m_b + m_c + m_2) + d_1 m_1}{m_a + m_b + m_c + m_1 + m_2},$$

$$r_2 = \frac{l_2 m_c + d_2 m_2}{m_b + m_c + m_2},$$

where r_1 and r_2 are the distance of the string positions from mass A and mass B, respectively; l_1 and l_2 are the lengths of rod 1 (rod with mass A) and rod 2 (rod with mass B and mass C), respectively; m_1 and m_2 are the masses of rods 1 and rod 2, respectively; and d_1 and d_2 are the distances from mass A and mass B to the centers of mass of rod 1 and rod 2, respectively.

SAMPLE DATA

Mass of rod 1: m_1 = 25.90(g)

Length of rod 1: l_1 = 52.10(cm)

Center of mass of rod 1: d_1 = 25.70(cm)

Mass of rod 2: m_2 = 20.60(g)

Length of rod 2: l_2 = 50.80(cm)

Center of mass of rod 2: d_2 = 25.00(cm)

Mass of mass A: m_A = 59.70(g)

Mass of mass B: m_B = 55.00(g)

Mass of mass C: m_C = 70.00(g)

Predicted hanging position on rod 1: 35.69(cm)

Measured hanging position on rod 1: 35.67(cm)

Predicted hanging position on rod 2: 27.96(cm)

Measured hanging position on rod 2: 27.90(cm)

LAB 6, PROBLEM 7: STATIC EQUILIBRIUM

PURPOSE

- To present the idea of balancing torque and forces in a familiar setting. This is to be done only if the students don't have a clear understanding of static equilibrium after doing the Mobile lab.

EQUIPMENT

String, clamp, pulley, aluminum channel, (normal) hanging mass set, large hanging mass set

TEACHING TIPS

- The aluminum channel has a uniform mass density, so it should be easy for the students to find the center of mass.
- Building a crane might be common sense for some people. To discourage them from building the crane first and then predicting the results, you should keep the masses until you are satisfied that they have completed the prediction.

- You will need to decide which masses to give to each group. Mix it up. Also, give each group different values for the angle between the support line and the rod.
- If the students mark the aluminum for the string placements, ask them to erase the marks when they are done. Don't encourage the students to make marks, but don't discourage it either.
- The prediction equations are messy, but every term is identifiable and the crane won't balance if they leave out a term, so expect good results. Note that the torque equation is the only one that's really needed, but you should have the students write down the force equations if they exhibit insufficient understanding of static equilibrium. The final form should be expressed in terms that the students can measure in the lab (e.g., mass and length).

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Torque is mystical to most students. Beware of students simply summing up all the torque without taking the direction of rotation or angle into consideration.

PREDICTION AND WARM-UP QUESTIONS

$$\theta = \arctan\left(\frac{W_A d_A + \frac{1}{2} mgd}{m_B g d_B}\right),$$

where W_A is the weight of object A, m_B is the mass of object B; m is the mass of the aluminum channel; $d_A (d_B)$ is the distance between pivot and the point where the string from object A(B) is connected to the bar; and d is the length of the channel.

SAMPLE DATA

$d_A = 33.2$ (cm), $d_B = 23.6$ (cm), $d = 36.8$ (cm), $m = 160.6$ (g), $m_B = 196$ (g)

m_A (g)	50	100	150
Predicted angle θ (degree)	44.93	53.6	59.76
Measured angle θ (degree)	45.14	54.95	60.56

TA Lab Evaluations

Physics 1301 Lab 6: Rotational Dynamics

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to **labhelp@physics.umn.edu**, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

____

____

____

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

____

Do you have additional comments regarding student learning and these labs?

____

____

____

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room

Was the room kept neat and clean by your class and other classes? (circle one) yes / no

Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

____

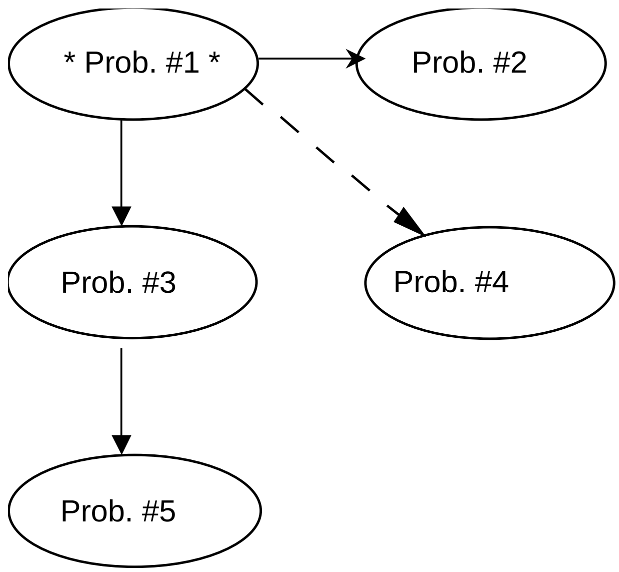
____

____

LABORATORY 7: MECHANICAL OSCILLATIONS

The purpose of this lab is to familiarize the students with the oscillatory motion caused by springs exerting a force on an object. In this lab students will use different methods to determine the spring constant and investigate what quantities determine the oscillation frequency of system. This lab also should help the students review some knowledge like kinetics, dynamics, energy that they have learned in previous labs.

By looking at the flow chart you can see that there is only one required problem in this lab. Problem #5 must follow Problem #3 since it need some parameter (natural frequency) from Problem #3.



GENERAL TEACHING TIPS

- Use the soft springs
- The elastic limit of oscillation springs is 60cm for the longer springs, 30cm for the shorter. Don't exceed individual spring limits during the experiment.

BY THE END OF THIS LAB, YOUR STUDENTS SHOULD BE ABLE TO

- Explain qualitatively the behavior of oscillating system.
- Describe quantitatively the influence of physical quantities that determine the period of the oscillatory motion.
- Apply mathematical method that works in describing oscillatory motion.
- Describe qualitatively the effect of additional forces on an oscillator's motion.

THINGS TO CHECK OUT BEFORE TEACHING THIS LAB

- Check every wheel for every plastic cart to see if the wheel can last rotating at least two seconds by a gentle push.
- Make sure no magnets at the both end of carts.
- For Problem #4, try different hanging masses but avoid passing the elastic limit of springs. Check the pulley to make sure it can rotate freely without binding. Replace any that don’t work.

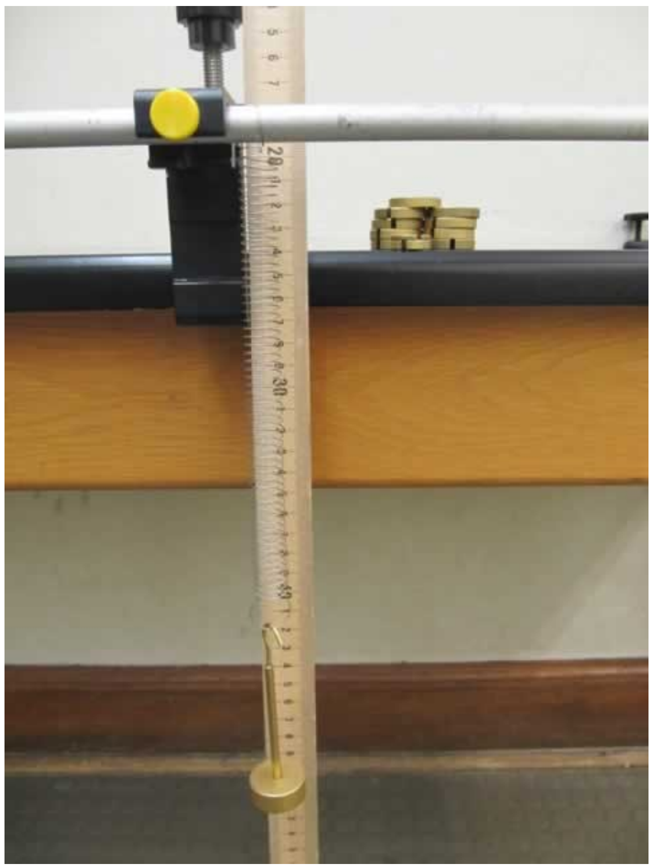
Lab 7, Problem 1: Measuring a Spring Constant

Purpose

- To familiarize students with the properties of a spring and the simple oscillation motion driven by a spring.

Equipment

Clamp, rod, spring, hanging mass set, meter stick



Teaching Tips

- Be sure not pass the elastic limit of springs. The hanging mass should be less than 200 g.
- During measuring, fix the top of the spring. Don't let it slide along ring stand. Try to keep spring-object system moving vertically without wobbling. Especially avoid spring-object system shake frontward and backward.
- Choose the reference point at the mass holder not at the spring since the spring will stretch during oscillation.

- For method #2, when digitizing data, it is better to start at the maximum displacement from the equilibrium position. Students need to collect the data of at least two complete periods.
- For method #2, students will use a lot of time to find the fit equations. They may need your help to get parameters in fit equations from graphs. (When we developed this experiment we took about 20 minutes to analyze data for one hanging mass.) If time is not enough, just choose one hanging mass.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students do not realize the spring constant is a property of a spring. They may think the spring constant will change with different hanging mass. The relationship between oscillation period and spring constant is also difficult to them.

PREDICTION AND WARM-UP QUESTIONS

Considering the uncertainty, the spring constants are the same for both methods. (about 3 N/m)

The period, T, of oscillation is given by the expression

$$T = 2\pi\sqrt{\frac{m}{k}},$$

where m is the mass of the hanging object at the free end of a spring, k is the spring constant of springs.

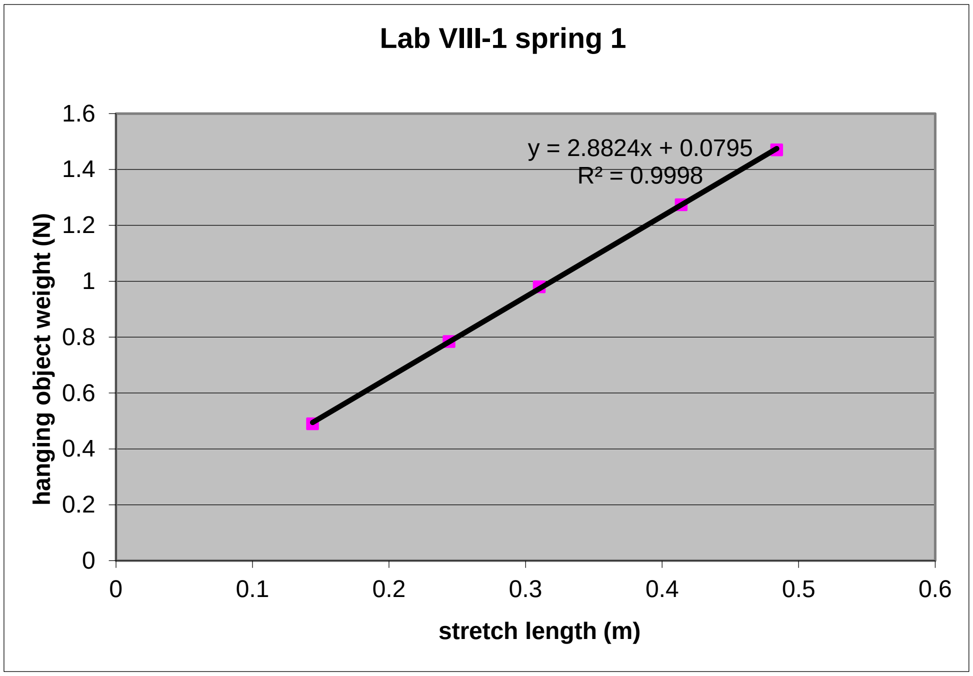
SAMPLE DATA

The printouts for the measurements of all oscillation periods are included at the end of following sample data.

METHOD 1 (STATIC APPROACH):

Spring 1:

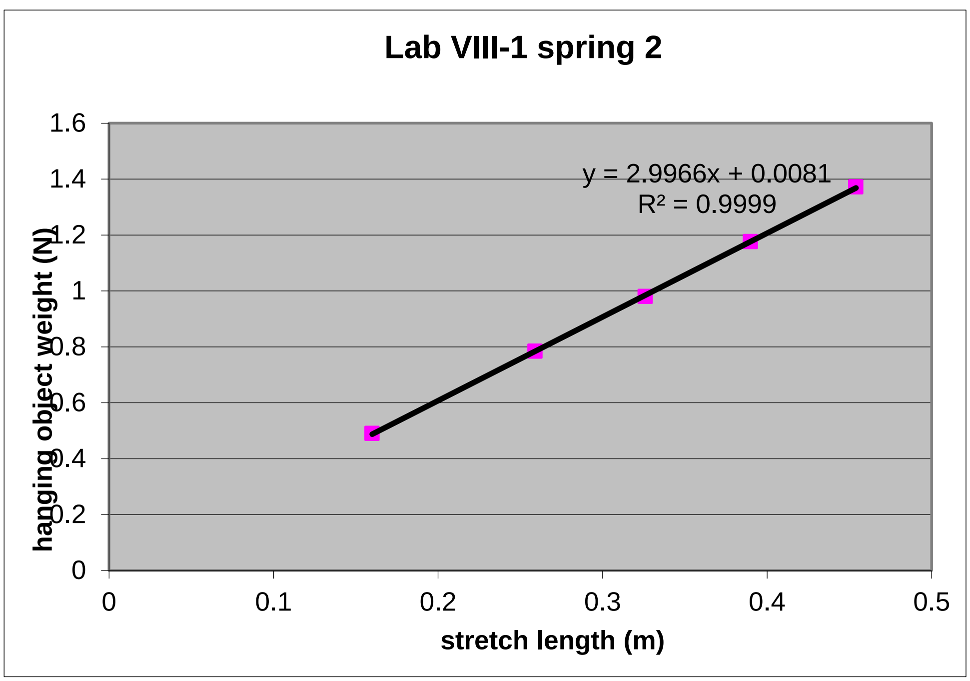
Stretch length d (cm)	14.4	24.4	31	41.4	48.4
Mass of object m (g)	50	80	100	130	150



Spring constant $k_1 = 2.882$ (N/m).

Spring 2:

Stretch length d (cm)	16	25.9	32.6	39	45.4
Mass of object m (g)	50	80	100	120	140



Spring constant $k_2 = 2.997$ (N/m).

METHOD 2 (DYNAMIC APPROACH):

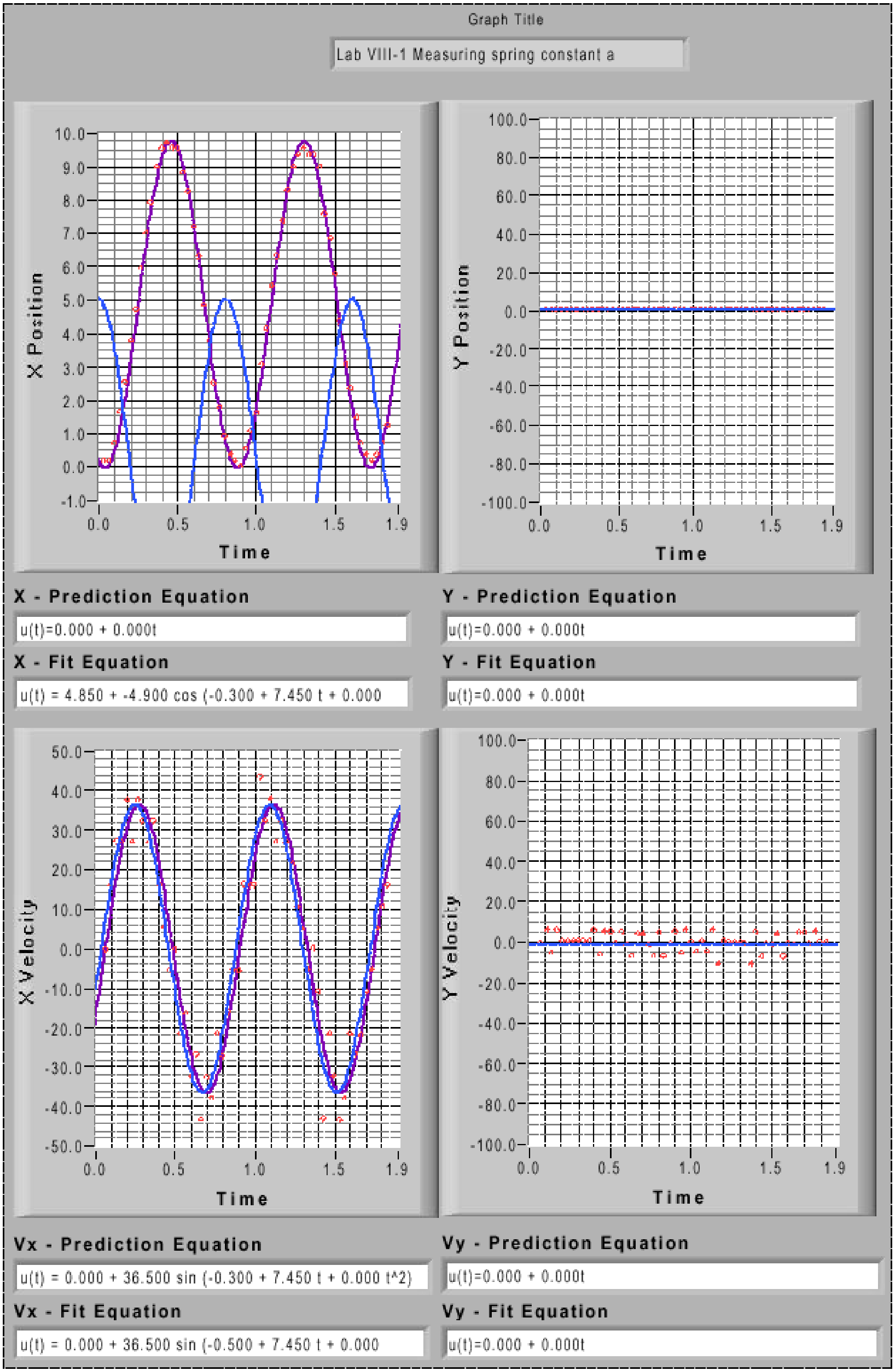
Mass of hanging object: $m = 50$ (g),

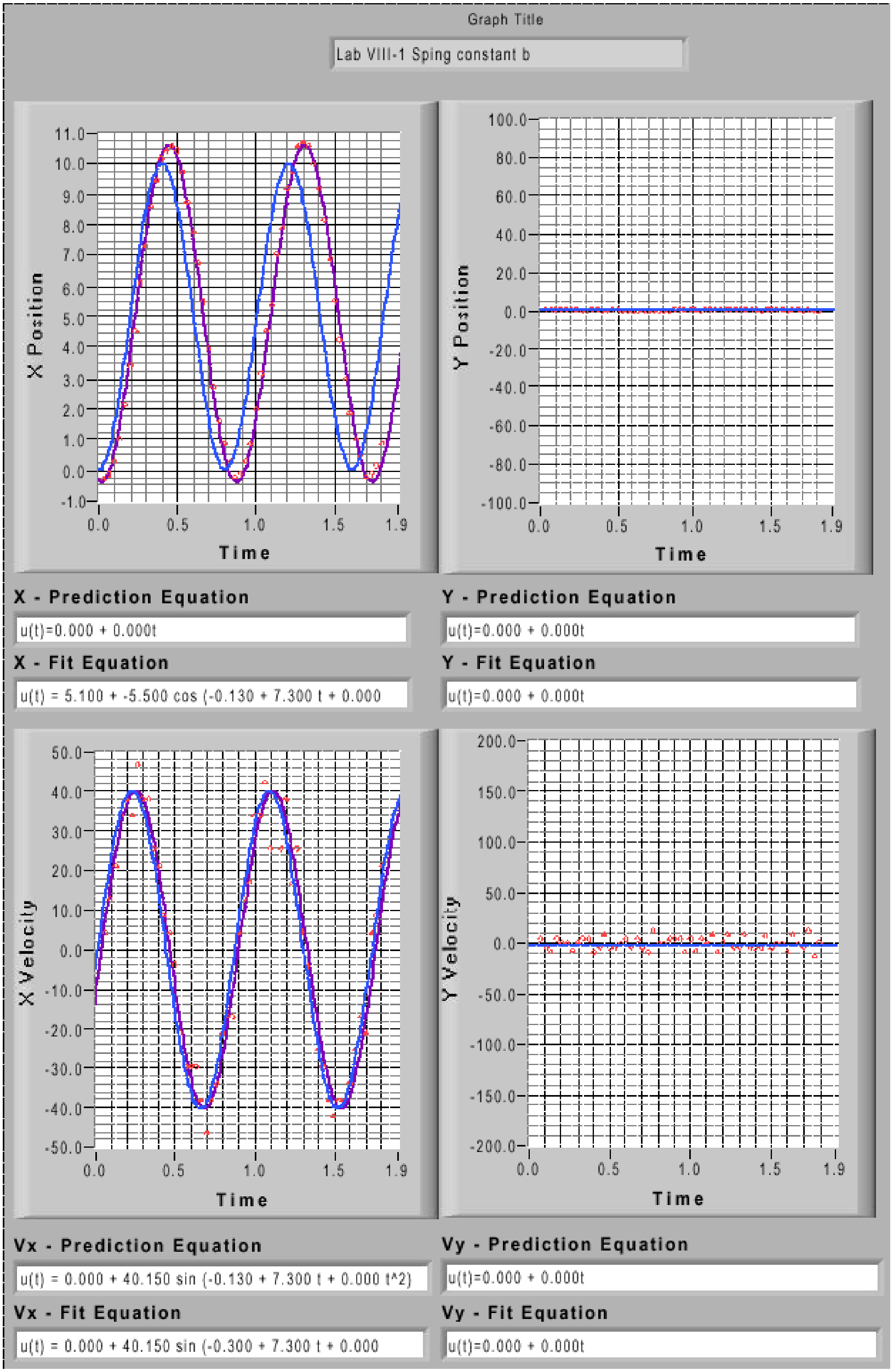
Measured oscillation period for spring 1: $T_1 = 0.843$ (s),

Measured oscillation period for spring 1: $T_2 = 0.860$ (s),

Calculated $k_1 = 2.775$ (N/m),

Calculated $k_2 = 2.665$ (N/m).


Graph Title
Lab VIII-1 Measuring spring constant a
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 4.850 + -4.900 cos (-0.300 + 7.450 t + 0.000
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 36.500 sin (-0.300 + 7.450 t + 0.000 t^2)
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t) = 0.000 + 36.500 sin (-0.500 + 7.450 t + 0.000
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VIII-1 Sping constant b
X Position
Time
Y Position
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 5.100 + -5.500 cos (-0.130 + 7.300 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Y Velocity
Vx - Prediction Equation
u(t) = 0.000 + 40.150 sin (-0.130 + 7.300 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + 40.150 sin (-0.300 + 7.300 t + 0.000
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

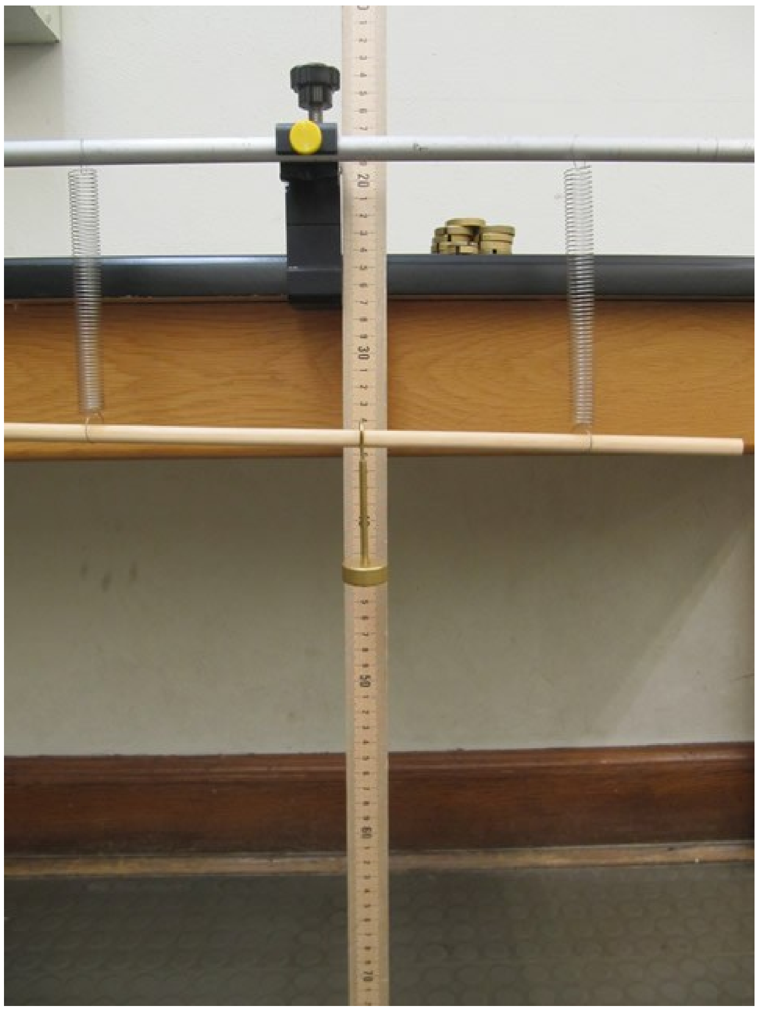
LAB 7, PROBLEM 2: THE EFFECTIVE SPRING CONSTANT

PURPOSE

- To familiarize students with the properties of a spring furthermore and research the oscillation motion driven by different spring configurations.

EQUIPMENT

Clamp, metal rod, wooden rod, two springs, hanging mass set



TEACHING TIPS

- Using method 2 of Problem 1 to measure the effective spring constants. Be sure not pass the elastic limit of springs.
- Keep spring-object system moving vertically without wobbling. Especially avoid spring-object system shake frontward and backward.

- For the side-by-side case, don't forget to let students consider the mass of the wood rod that connect the bottom of two springs and the mass holder.
- For end-to-end case, choosing smaller hanging masses is better.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

The concept of effective spring constant is "new" for students. They may think the effective spring constant is always bigger than the spring constant of either spring no matter which configuration of two springs.

PREDICTION AND WARM-UP QUESTIONS

SIDE-BY-SIDE CONFIGURATION

$k' = k_1 + k_2$,

Derivation for this configuration is straightforward – total force is sum of two forces.

END-TO-END CONFIGURATION

$$k' = \frac{k_1 k_2}{k_1 + k_2}.$$

Derivation: Let $y = y_1 + y_2$, then Newton's Second Law is

$$m\Delta\ddot{y} = \Delta F_2 = -k_2 \Delta y_2 \Rightarrow \Delta\ddot{y}_1 + \Delta\ddot{y}_2 = -\frac{k_2}{m}\Delta y_2.$$

Applying Newton's Third Law, one gets

$$k_2 \Delta y_2 = k_1 \Delta y_1.$$

Then

$$\frac{k_2}{k_1}\Delta\ddot{y}_2 + \Delta\ddot{y}_2 = -\frac{k_2}{m}\Delta y_2 \Rightarrow \Delta\ddot{y}_2 = -\frac{k_2 k_1}{m(k_2 + k_1)}\Delta y_2.$$

Finally, let's introduce effective spring constant k' equal to $\frac{k_1 k_2}{k_1 + k_2}$

Period of oscillation: $T = 2\pi\sqrt{\frac{m}{k'}}$

where m is the mass of the hanging object at the free end of spring configurations. k_1 and k_2 are the spring constants of two oscillation springs. $k^{/}$ is the effective spring constant for spring configurations.

SAMPLE DATA

The printouts for the measurements of all oscillation periods are included at the end of following sample data.

$k_1 = 2.775\,(\text{N/m})$, $k_2 = 2.665\,(\text{N/m})$.

SIDE-BY-SIDE CONFIGURATION

Mass of hanging object (including mass of the wooden rod): $m = 61\,(\text{g})$,

Measured period: $T = 0.686\,(\text{s})$,

Predicted effective spring constant: $k^{/} = k_1 + k_2 = 5.44\,(\text{N/m})$,

Measured effective spring constant: $k^{/} = 5.11\,(\text{N/m})$.

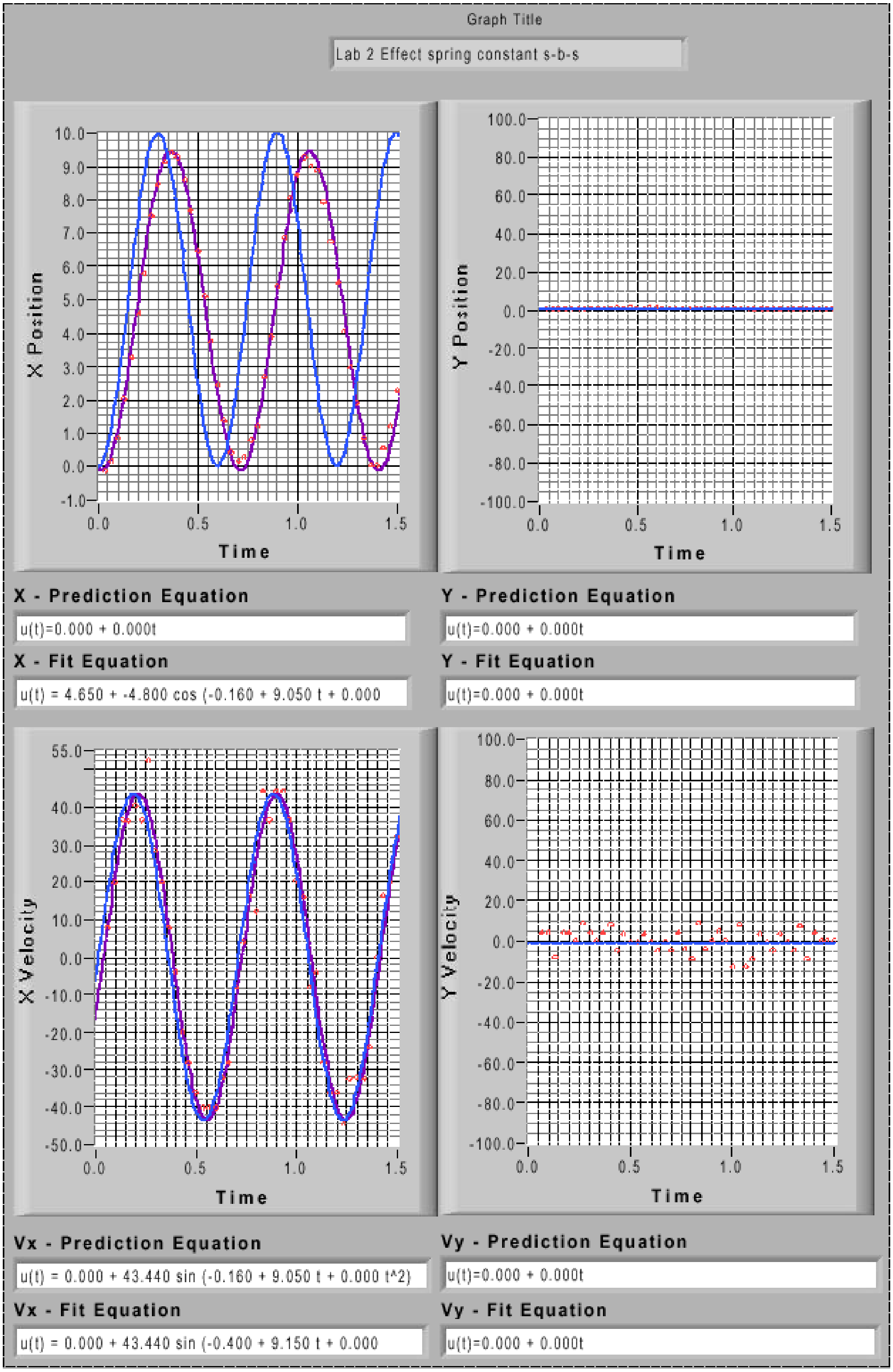
END-TO-END CONFIGURATION

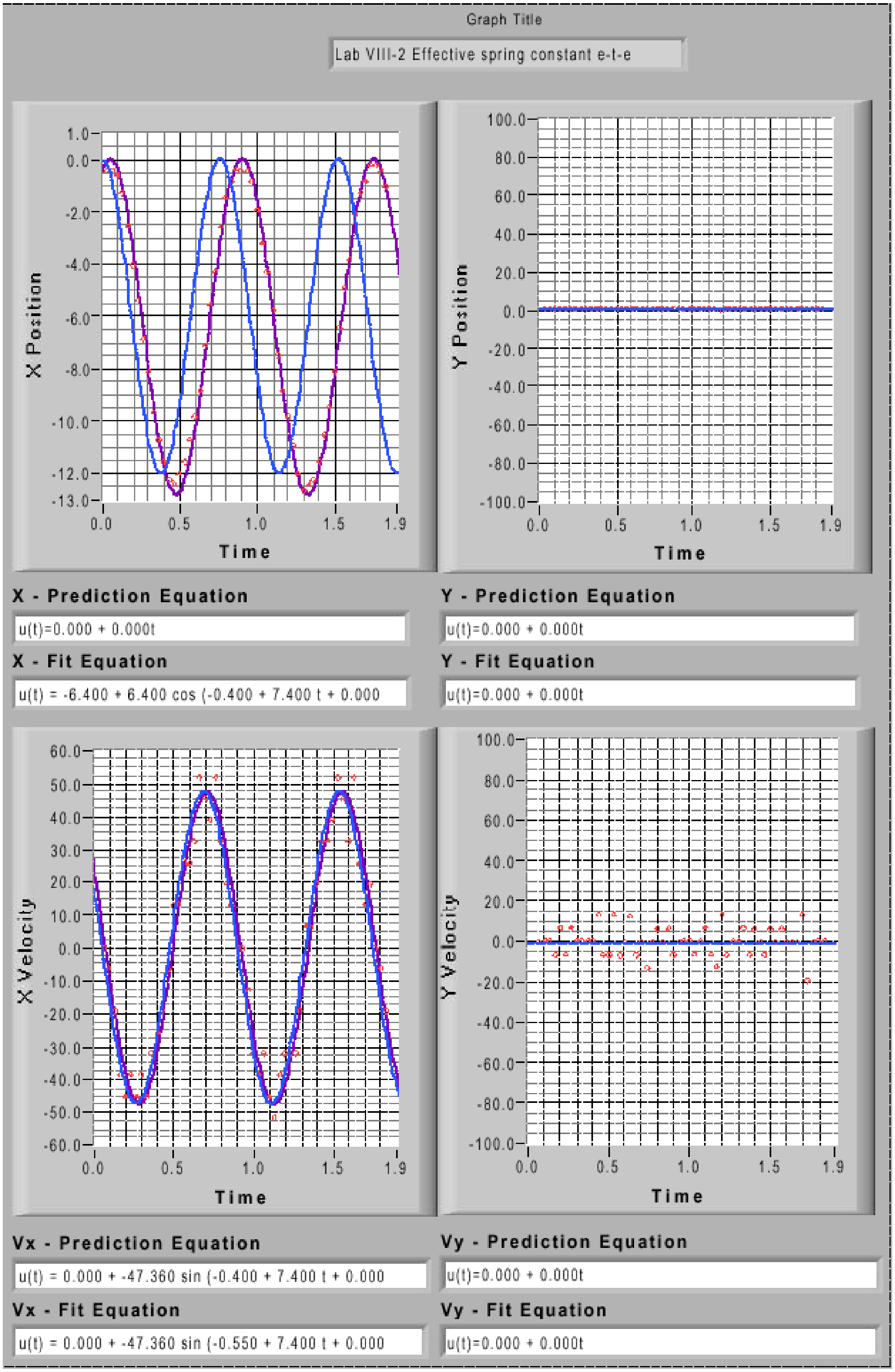
Mass of hanging object: $m = 20\,(\text{g})$,

Measured period: $T = 0.849\,(\text{s})$,

Predicted effective spring constant: $k^{/} = k_1 k_2 /(k_1 + k_2) = 1.36\,(\text{N/m})$,

Measured effective spring constant: $k^{/} = 1.10\,(\text{N/m})$.


Graph Title
Lab 2 Effect spring constant s-b-s
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 4.650 + -4.800 cos (-0.160 + 9.050 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 43.440 sin (-0.160 + 9.050 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + 43.440 sin (-0.400 + 9.150 t + 0.000
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VIII-2 Effective spring constant e-t-e
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = -6.400 + 6.400 cos (-0.400 + 7.400 t + 0.000
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -47.360 sin (-0.400 + 7.400 t + 0.000
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t) = 0.000 + -47.360 sin (-0.550 + 7.400 t + 0.000
Vy - Fit Equation
u(t)=0.000 + 0.000t

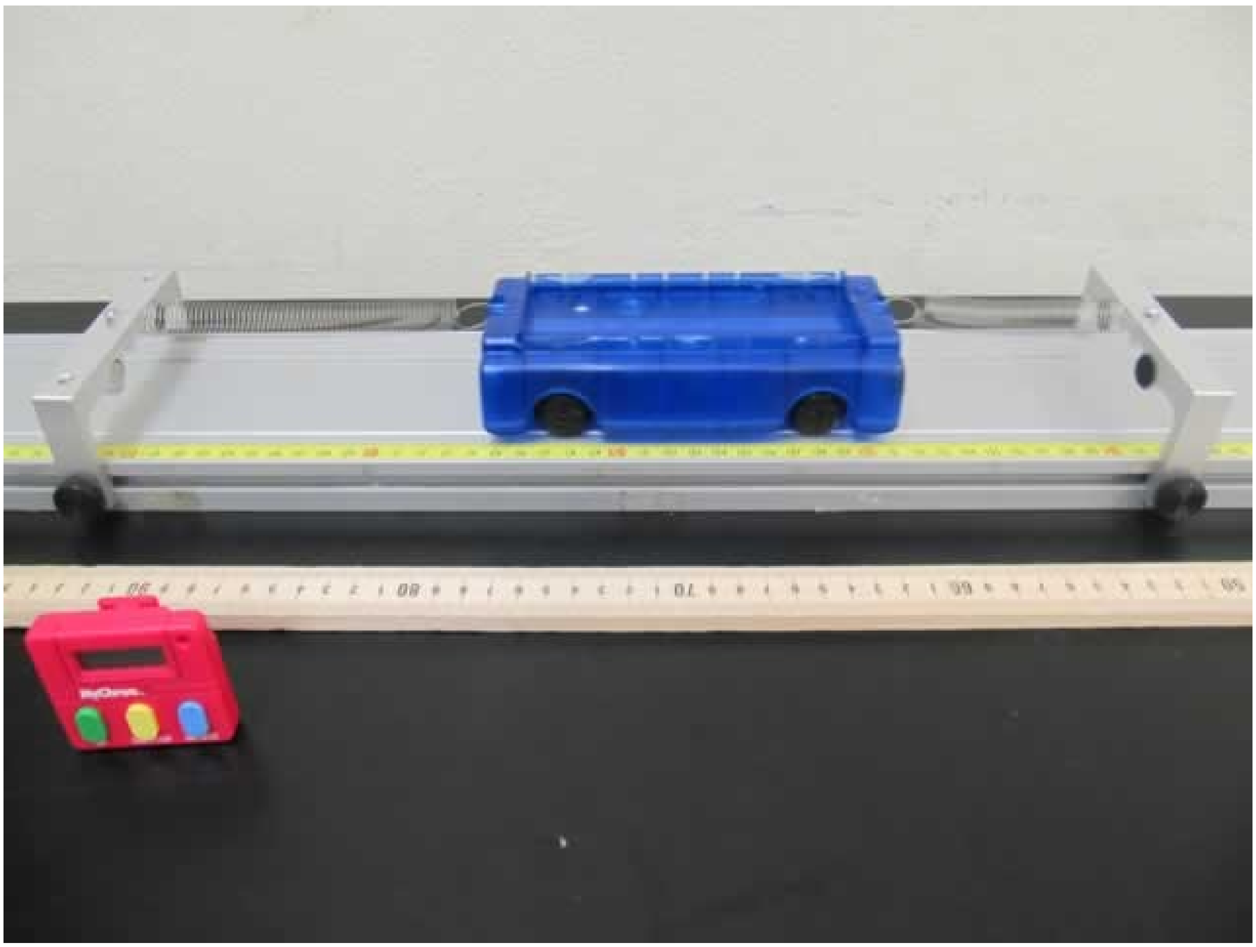
LAB 7, PROBLEM 3: OSCILLATION FREQUENCY WITH TWO SPRINGS

PURPOSE

- To describe quantitatively the influence of physical quantities which determine the oscillation frequency for a complex spring-cart system.

EQUIPMENT

Track, cart, two end stops, two springs, meter stick, stopwatch



TEACHING TIPS

- Using strings to fix one top of the spring at the end stop and another top at one end of the cart.
- Try a longer stretched distance to start oscillation but make sure not pass the elastic limit of the springs.

- Require students to record at least 3 periods of oscillatory motion of the cart in their video and analyze the data of two complete periods. During digitizing data, choose the moment when cart arrives at its maximum distance from the equilibrium position as the beginning.
- Explain to student that the amplitude of oscillation will decreases because of friction but the frictional force does not change the oscillation frequency.

PREDICTION AND WARM-UP QUESTIONS

The frequency, f, of oscillation is given by the expression

$$f = \frac{1}{2\pi}\sqrt{\frac{k_1 + k_2}{m}},$$

where m is the mass of the cart. k_1 and k_2 are the spring constants of two oscillation springs. Derivation of this formula is straightforward if one realizes that the change in forces from the equilibrium position are relevant (see also Sample Lab #3 for more details):

$$\Delta F_{1x} + \Delta F_{2x} = m\frac{d^2x}{dt^2}$$

The changes in forces ΔF_{1x} and ΔF_{2x} can be found using Hook's Law

$$\Delta F_{1x} = F_{1x} - F_{1x}^{eq} = -k_1(x - x_0)\ \Delta F_2 = F_{2x} - F_{2x}^{eq} = -k_2(x - L_2) + k_2(x_0 - L_2) = -k_2(x - x_0),$$

where L_2 is the relaxed length of the spring and x_0 is equilibrium position. Then

$$\frac{d^2x}{dt^2} + \frac{(k_2 + k_1)}{m}(x - x_0) = 0$$

and so the frquency is

$$f = \frac{1}{2\pi}\sqrt{\frac{k_1 + k_2}{m}}.$$

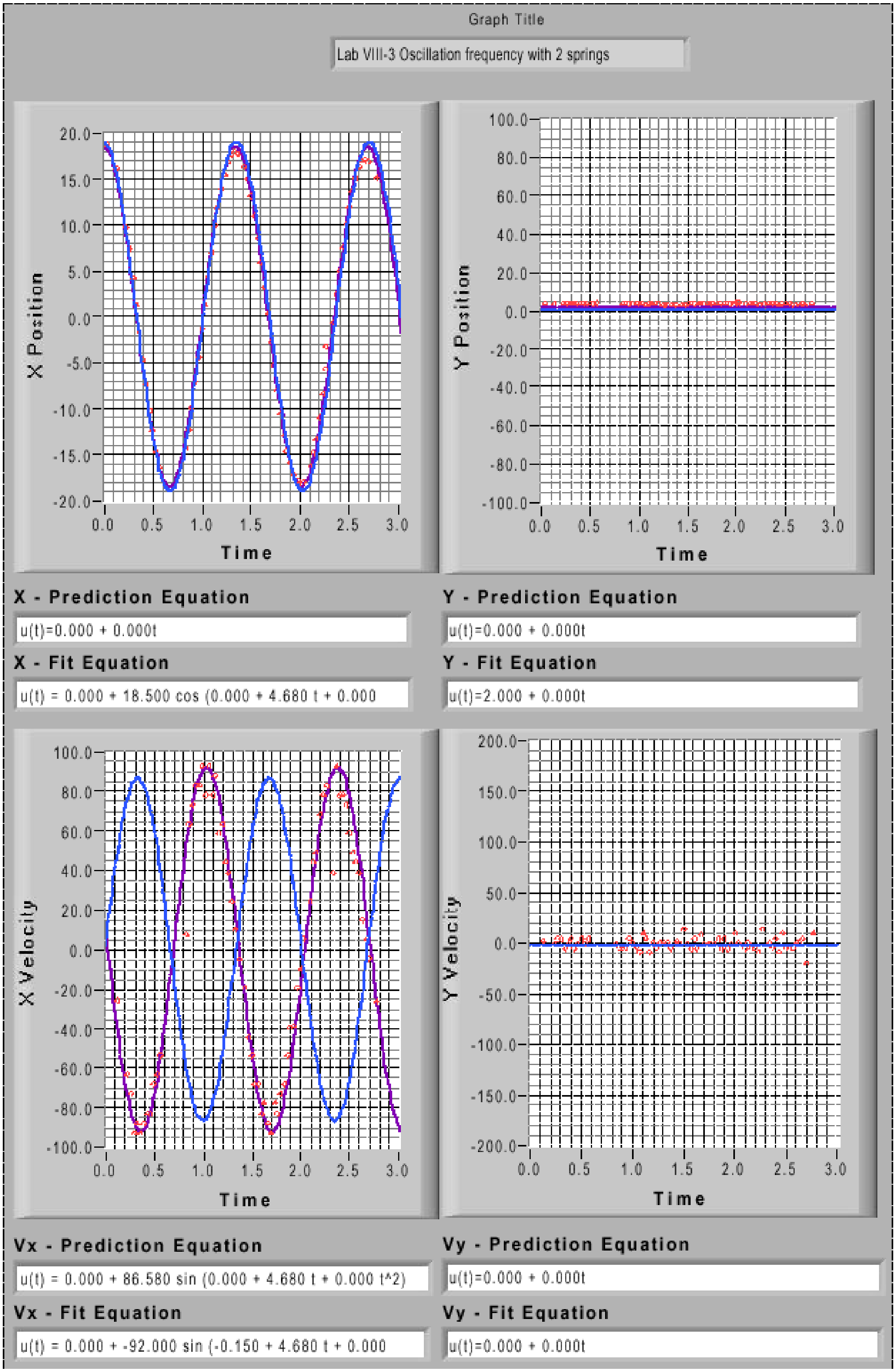
SAMPLE DATA

The printout for the measurement of oscillation frequency is included at the end of following sample data.

Mass of the cart: $m = 251.65$ (g),

$k_1 = 2.775$ (N/m), $k_2 = 2.665$ (N/m), Predicted frequency: $f = 0.740$ (Hz),

Measured frequency: $f = 0.745$ (Hz).


Graph Title
Lab VIII-3 Oscillation frequency with 2 springs
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 18.500 cos (0.000 + 4.680 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=2.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + 86.580 sin (0.000 + 4.680 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -92.000 sin (-0.150 + 4.680 t + 0.000
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

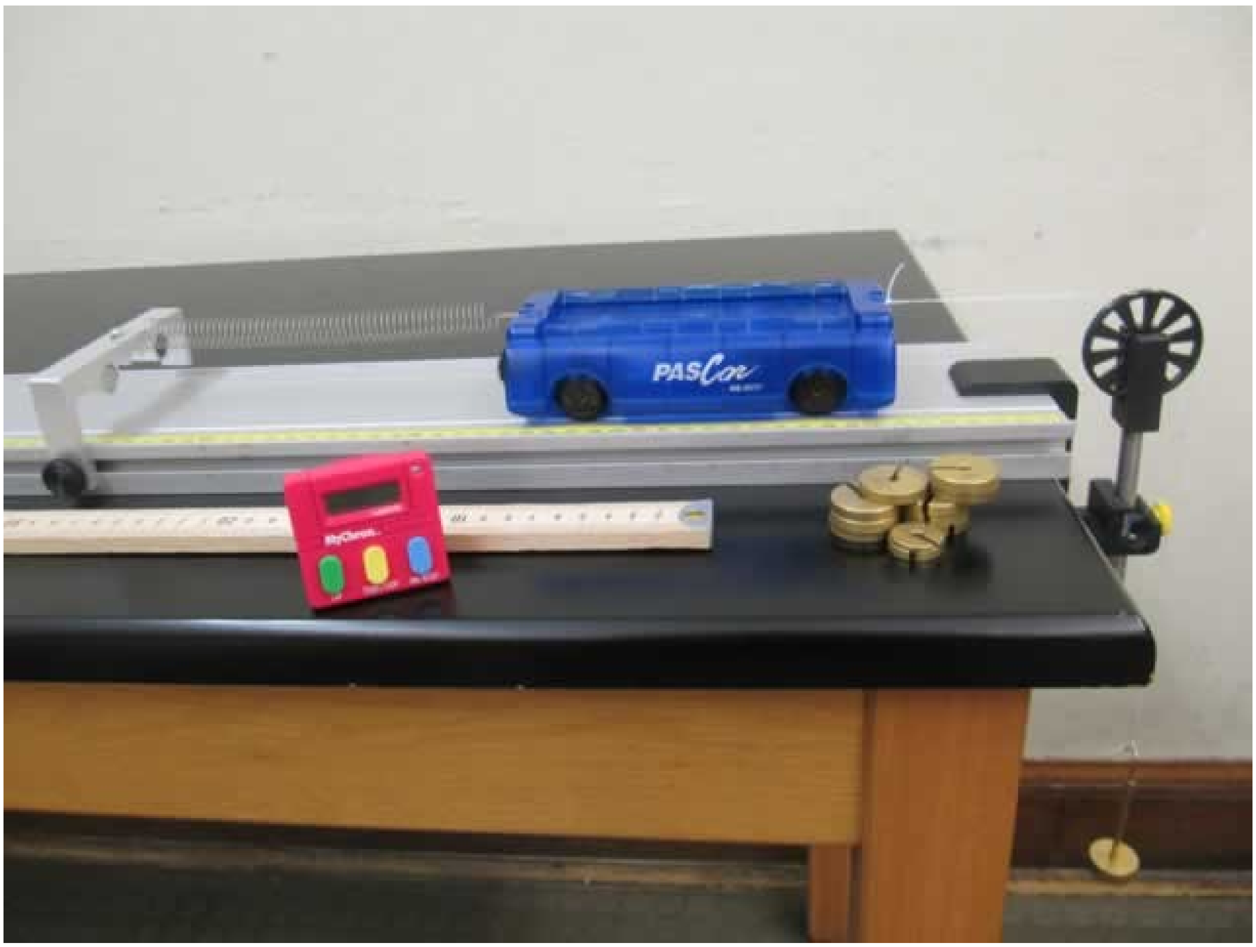
LAB 7, PROBLEM 4: OSCILLATION FREQUENCY OF AN EXTENDED SYSTEM

PURPOSE

- To describe quantitatively the influence of physical quantities that determine the oscillation frequency for an extended oscillation system.

EQUIPMENT

Track, end stop, cart, spring, string, pulley, clamp, hanging mass set, meter stick, stopwatch



TEACHING TIPS

- Change the hanging mass with a big rang (from 50 g to 200 g) but make sure the hanging mass should be less than 200 g.
- For different hanging masses, you need to adjust the position of end stop to demonstrate an obvious oscillation but make sure not pass the elastic limit of the springs.

- Require students to record at least 3 periods of oscillatory motion of the cart in their video and analyze the data of two complete periods. During digitizing data, choose the moment when cart arrives at its maximum distance from the equilibrium position as the beginning.
- The damping effect by friction is obvious in this experiment. Explain to student that the amplitude of oscillation will decreases because of friction but the frictional force does not change the oscillation frequency.

PREDICTION AND WARM-UP QUESTIONS

Oscillation frequency: $f = \frac{1}{2\pi}\sqrt{\frac{k}{m+M}}$,

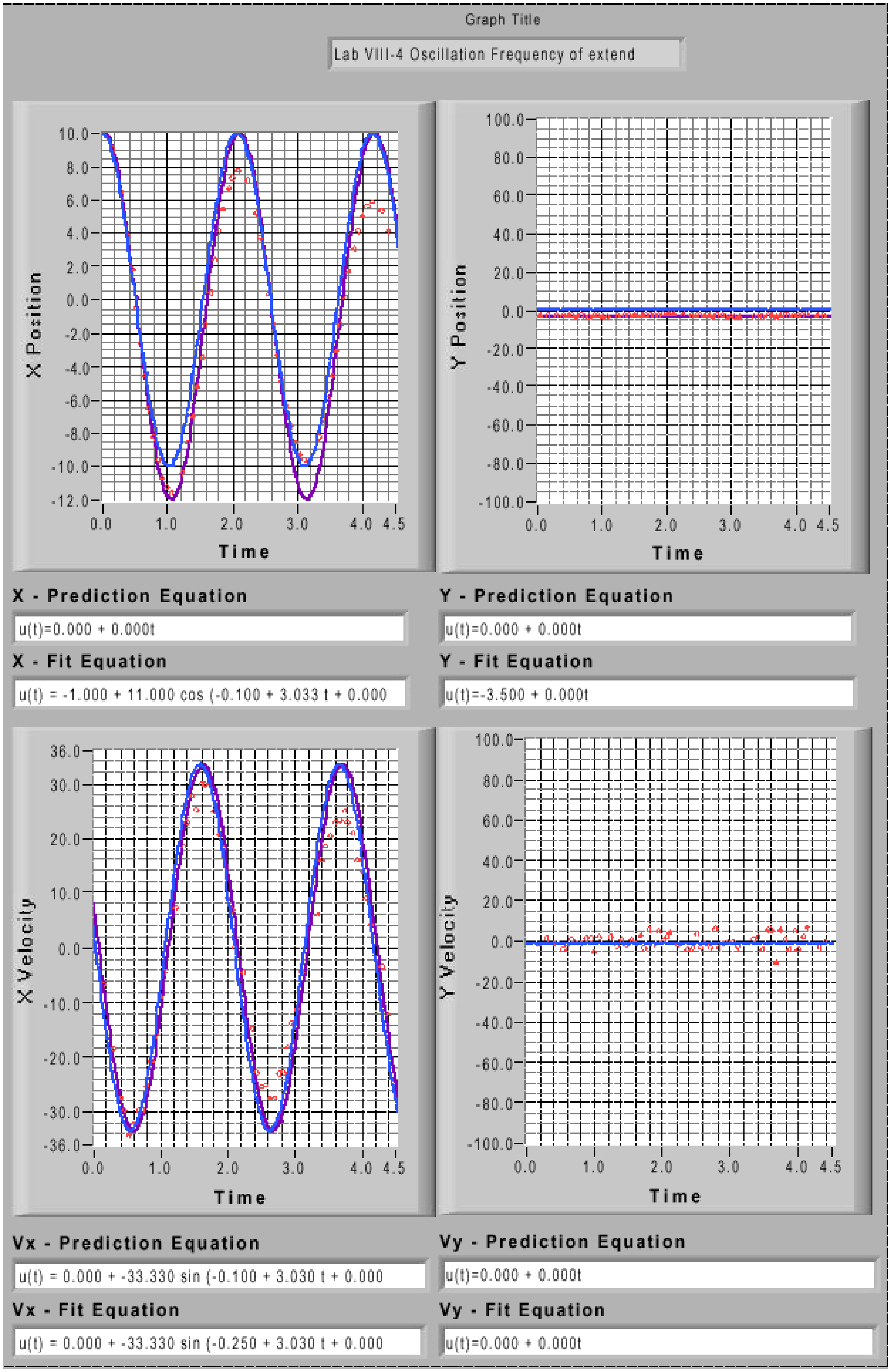
where m is the mass of the cart, k is the spring constant of an oscillation spring and M is the mass of the hanging object.

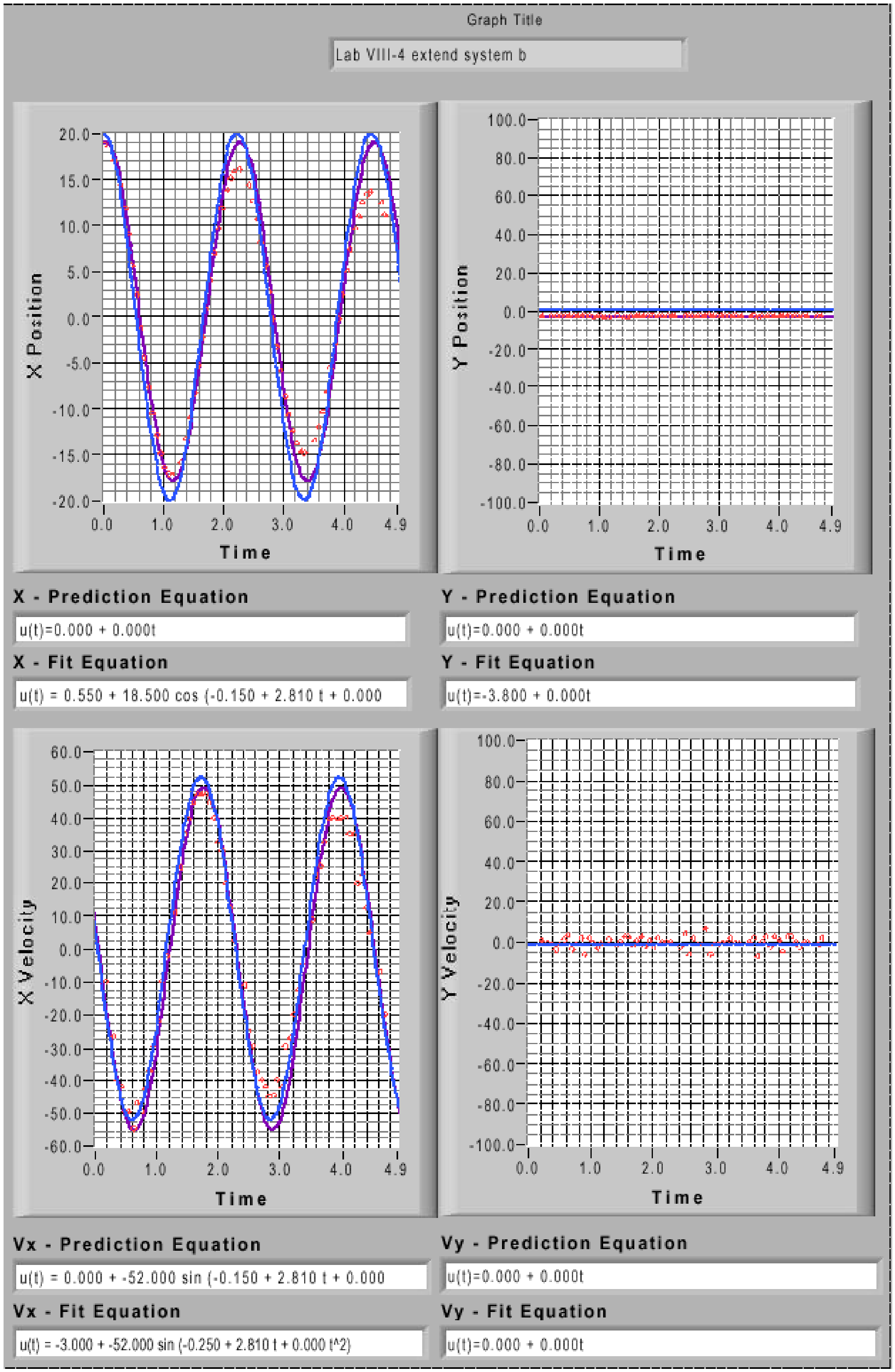
SAMPLE DATA

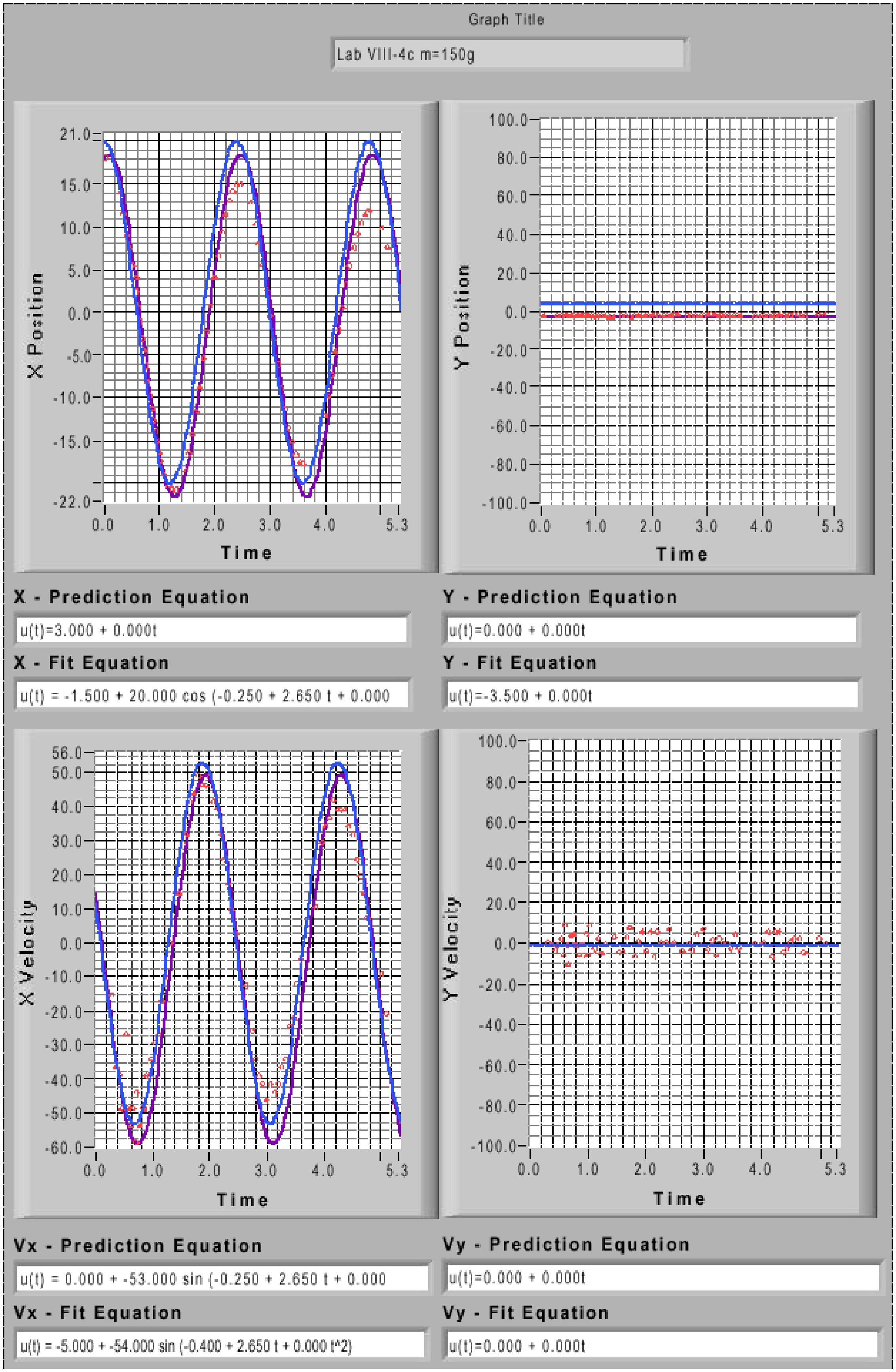
Mass of the cart: $m = 251.65$ (g),

Spring constant: $k = 2.775$ (N/m),

Mass of hanging object M (g)	50	100	150
Predicted frequency f (Hz)	0.483	0.447	0.419
Measured frequency f (Hz)	0.482	0.447	0.422


Graph Title
Lab VIII-4 Oscillation Frequency of extend
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = -1.000 + 11.000 cos (-0.100 + 3.033 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-3.500 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -33.330 sin (-0.100 + 3.030 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -33.330 sin (-0.250 + 3.030 t + 0.000
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VIII-4 extend system b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.550 + 18.500 cos (-0.150 + 2.810 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-3.800 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -52.000 sin (-0.150 + 2.810 t + 0.000
Vx - Fit Equation
u(t) = -3.000 + -52.000 sin (-0.250 + 2.810 t + 0.000 t^2)
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab VIII-4c m=150g
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=3.000 + 0.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = -1.500 + 20.000 cos (-0.250 + 2.650 t + 0.000
Y - Fit Equation
u(t)=-3.500 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t) = 0.000 + -53.000 sin (-0.250 + 2.650 t + 0.000
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t) = -5.000 + -54.000 sin (-0.400 + 2.650 t + 0.000 t^2)
Vy - Fit Equation
u(t)=0.000 + 0.000t

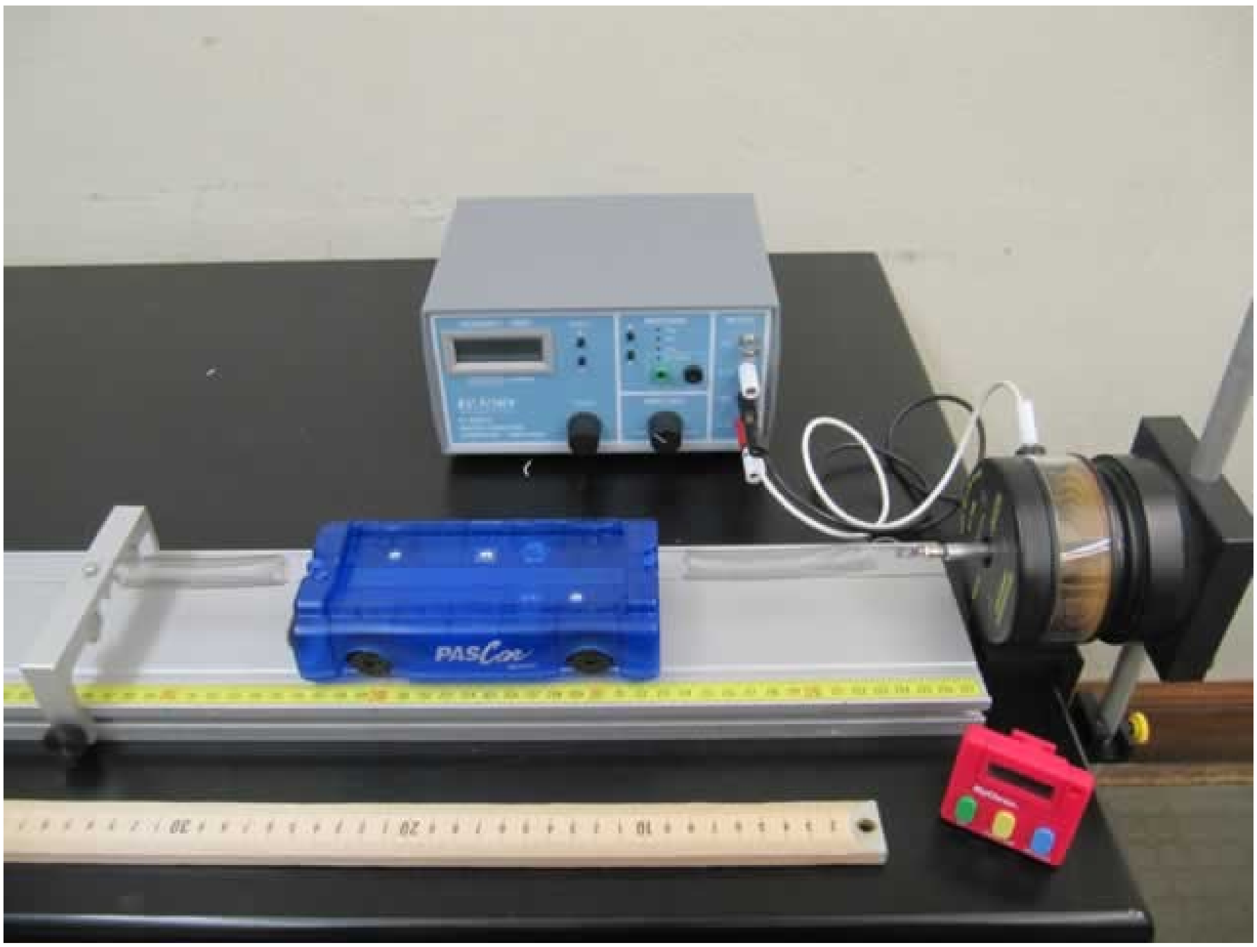
LAB 7, PROBLEM 5: DRIVEN OSCILLATIONS

PURPOSE

- To show students the resonance phenomena for a driven oscillation.

EQUIPMENT

Cart, track, end stop, spring, clamp, rod, driver, function generator, wires, meter stick, stopwatch



TEACHING TIPS

- Take the result in Problem #3 as the natural frequency.
- For low driving frequency, the cart may be bond by friction. You need to gently touch the cart to start it.
- Near the natural frequency, choose 5 ~ 6 data points with an interval of 0.005 Hz.
- For each frequency, restart the cart from rest.

DIFFICULTIES AND ALTERNATIVE CONCEPTIONS

Students may think the amplitude of oscillation is only dependent on the amplitude of driver and has nothing with the frequency of the mechanical driver. Another misconception is the amplitude of oscillation will increase with the frequency of mechanical driver.

PREDICTION AND WARM-UP QUESTIONS

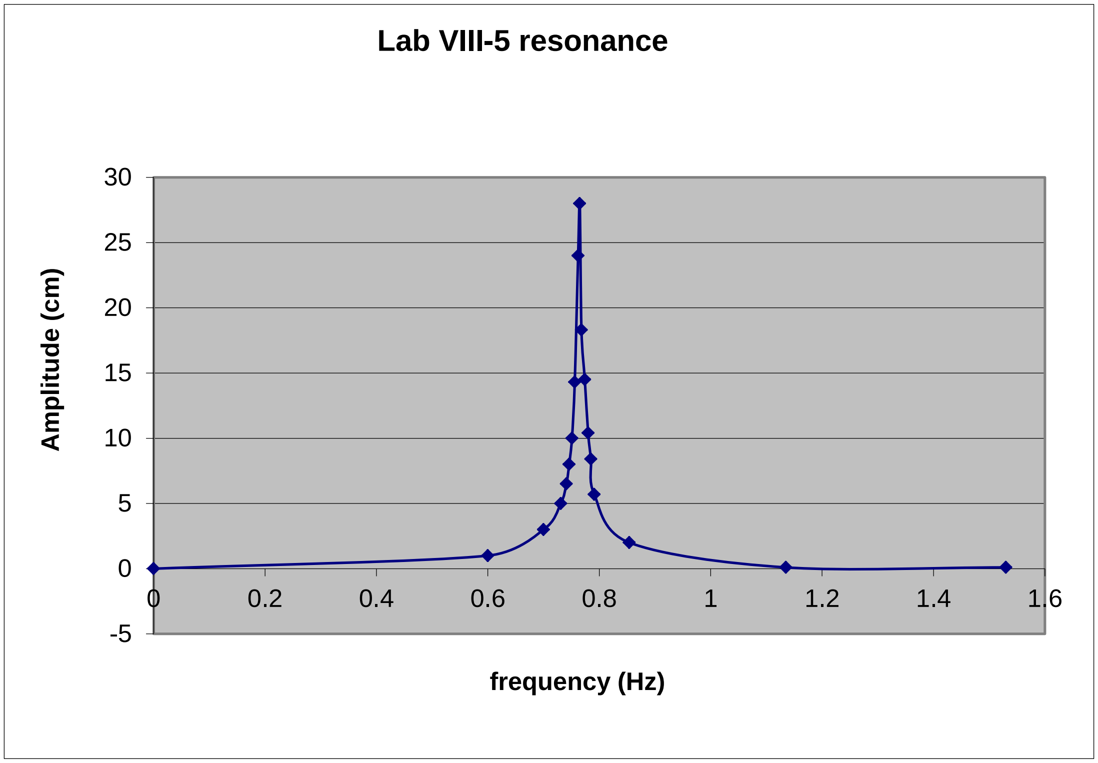
The amplitude-frequency sketch is like that in the textbook. When frequency of mechanical driver is equal to the natural frequency, we get the maximum amplitude, i.e. the resonance phenomena happen.

SAMPLE DATA

From the result of Problem #3, the natural frequency is 0.745 Hz.

Frequency f (Hz)	0	0.6	0.7	0.731	0.741	0.746	0.751	0.756	0.762
Amplitude A (cm)	0	1	3	5	6.5	8	10	14.3	24
Frequency f (Hz)	0.765	0.768	0.774	0.780	0.785	0.791	0.854	1.135	1.53
Amplitude A (cm)	28	18.3	14.5	10.4	8.4	5.7	2	0.1	0.1

Resonance occurred at $f = 0.765$ (Hz).



TA Lab Evaluations

Physics 1301 Lab 7: Mechanical Oscillations

We encourage you to report any problems with the lab immediately after completing it; please e-mail comments to **labhelp@physics.umn.edu**, including the topics below. You may also print out and complete this form, then turn it into the lab coordinator's mailbox in room 139.

Instructors' Pages

Did you find the instructors' pages useful? (Circle one.) yes / no

What additional information would you include in these pages?

____

____

____

Students

Did the students find these exercises: (circle one) enlightening / boring / fun / other

If other, what?

____

Do you have additional comments regarding student learning and these labs?

____

____

____

TA

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room

Was the room kept neat and clean by your class and other classes? (circle one) yes / no

Was the equipment functioning properly, or if not, could you fix it? (circle one) yes / no

Any other comments regarding the room and equipment?

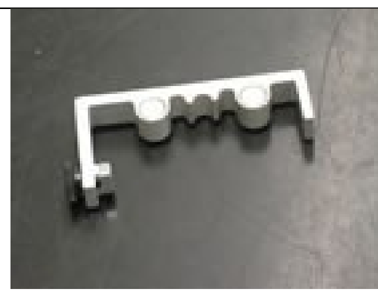
____

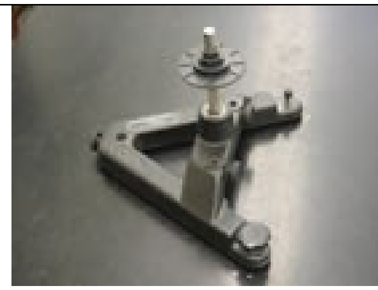
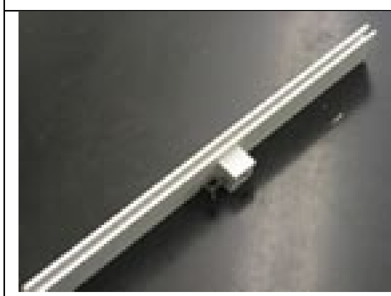
____

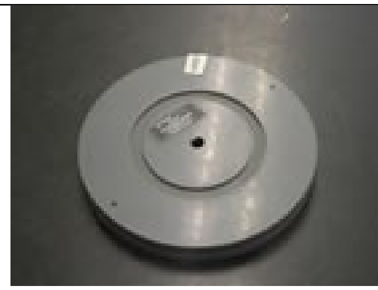
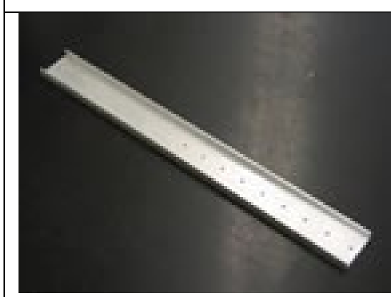
____

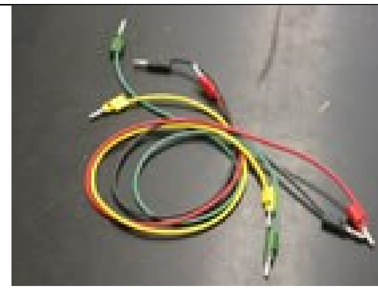
1301 EQUIPMENT GUIDE

Remember to submit a lab problem report using the link on the desktop of the lab workstations for any problems with the lab equipment. Some equipment is noted as being commonly available in supply closets on the second floor. If you take equipment, you still need to submit a problem report. Please encourage your students to keep all parts of equipment together. Mass sets should remain as sets. Nuts and bolts should be securely tightened after use. Common problems and potential quick fixes are noted for some equipment. Thanks for your help!

	**Toy Car** Replacements in second floor closet #8.		**Track** Tracks are left in the labrooms.
	**Stop Watch** Replacements in second floor closet #8.		**Meter Stick** Replacements in second floor closet #7.
	**Video Setup – IEEE 1394 Camera and Cable.** Replacements in second floor closet #8.		**Endstop** Replacements in second floor closet #8. Keep lock screw tight.
	**Wooden Block**		**Cart** Replacements in second floor closet #8.

	**Cart Mass**		**Elastic Thread** Replacements in second floor closet #8.
	**Ball Set**		**A-frame Base and Spindle (Rotational Base)** C- pins should be replaced if removed.
	**Rotating Platform** Keep thumb screw tightened.		**Pulley** Replacements in second floor closet #8.
	**Table / Pulley Clamp** Replacements in second floor closet #8**.** Keep thumb screw tightened.		**Scissors** Replacements in second floor closet #8.
	**Mass Set** Keep mass sets together as sets. (1×50g hangar, 9×20g, 1×10g & 1×5g)		**Tape and String** Replacements in second floor closet #8.

	**Friction Accessory** Keep parts together. Replacements in second floor closet #8 in cup.		**Friction Block**
	**Triple-beam Balance**		**Disk** Do not apply unnecessary pressure; disks will break if abused.
	**Inertial Ring**		**Wooden Dowel**
	**Aluminum (Crane) Channel**		**Spring** Replacements in second floor closet #8. Do not overstretch.
	**Metal Rod**		**Mechanical Oscillator** Check the fuse.

	**Function Generator**		**Banana Cable** Replacements in second floor closet #8**.**

<u>VIDEO ANALYSIS OF MOTION</u>

N.B.: The following document is taken verbatim from the students' lab manual. As such, it is written with the student as the intended audience ("you").

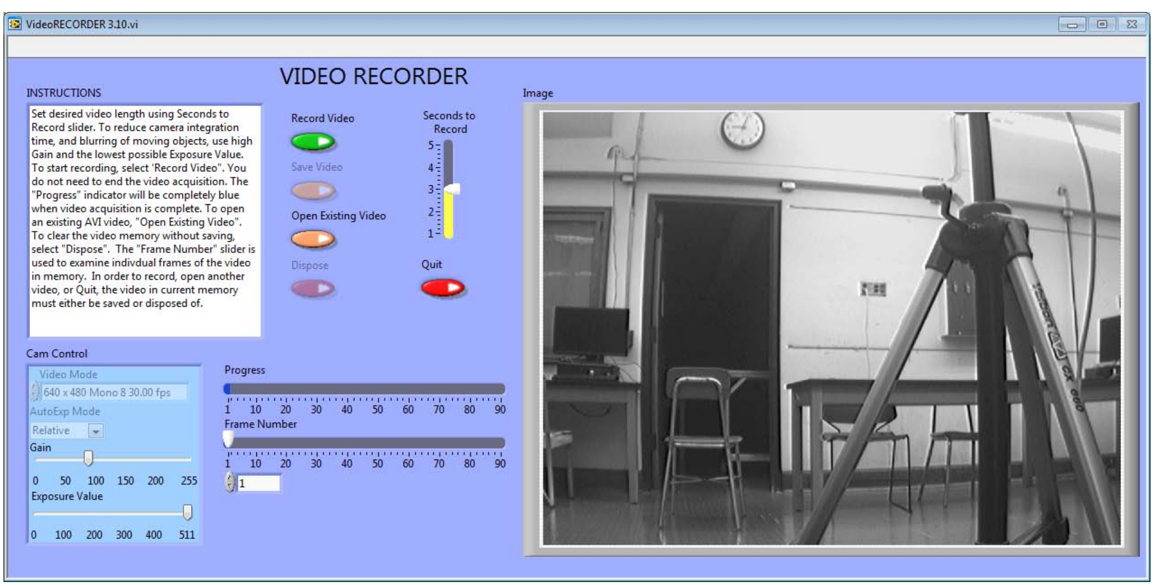
Analyzing pictures (movies or videos) is a powerful tool for understanding how objects move. Like most forms of data, video is most easily analyzed using a computer and data acquisition software. This appendix will guide a person somewhat familiar with Windows through the use of one such program: the *VideoRECORDER* video analysis application written in *LabVIEW™*. LabVIEW™ is a general-purpose data acquisition programming system. It is widely used in academic research and industry. We will also use LabVIEW™ to acquire data from other instruments throughout the year.

Using video to analyze motion is a two-step process. The first step is recording a video. This process uses the video software to record the images from the camera and compress the file. The second step is to analyze the video to get a kinematic description of the recorded motion.

MAKING VIDEOS

After logging into the computer, open the video recording program by double clicking the icon on the desktop labeled *VideoRECORDER*. A window similar to the picture below should appear.

If the camera is working, you should see a "live" video image of whatever is in front of the camera. (See your instructor if your camera is not functioning and you are sure you turned it on.) By adjusting the lens on the video camera, you can alter both the magnification and the sharpness of the image until the picture quality is as good as possible.



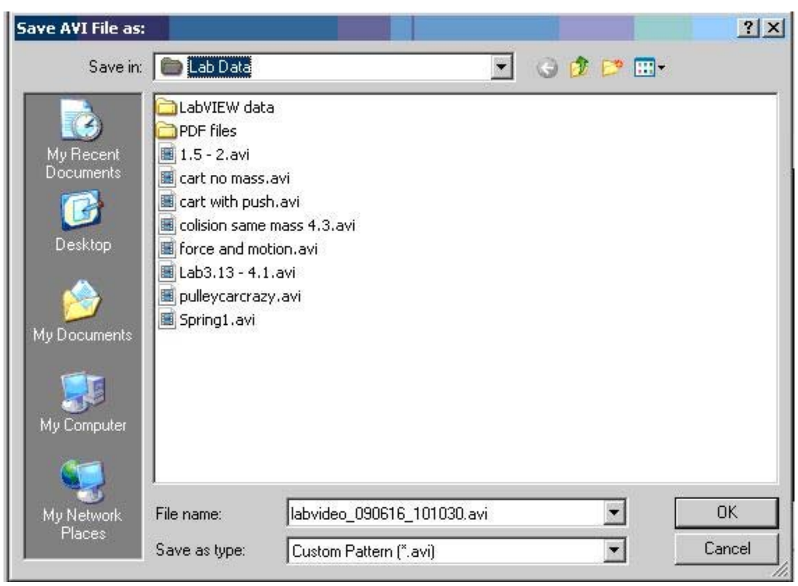
The controls are fairly self-explanatory; pressing the *Record Video* button begins the process of recording a 5-second video image. While the video is recording, the blue *Progress* bar beneath the video frame grows. Once you have finished recording, you can move through the video by dragging the *Frame Number* slider control. If you are not pleased with your video recording, delete it by pressing the *Dispose* button.

You may notice that the computer sometimes skips frames. You can identify the dropped frame by playing the video back frame by frame. If recorded motion does not appear smooth, or if the object skips irregularly, then frames are probably missing. If the computer is skipping frames, speak with your instructor.

While you are recording your video, you should try to estimate the kinematic variables you observe, such as the initial position, velocities, and acceleration. The time with the unit of second is shown in the VideoRECORDER window, in the box below the Frame Number slider. These values prove very useful for your prediction equations. Be sure to record your estimates in your journal.

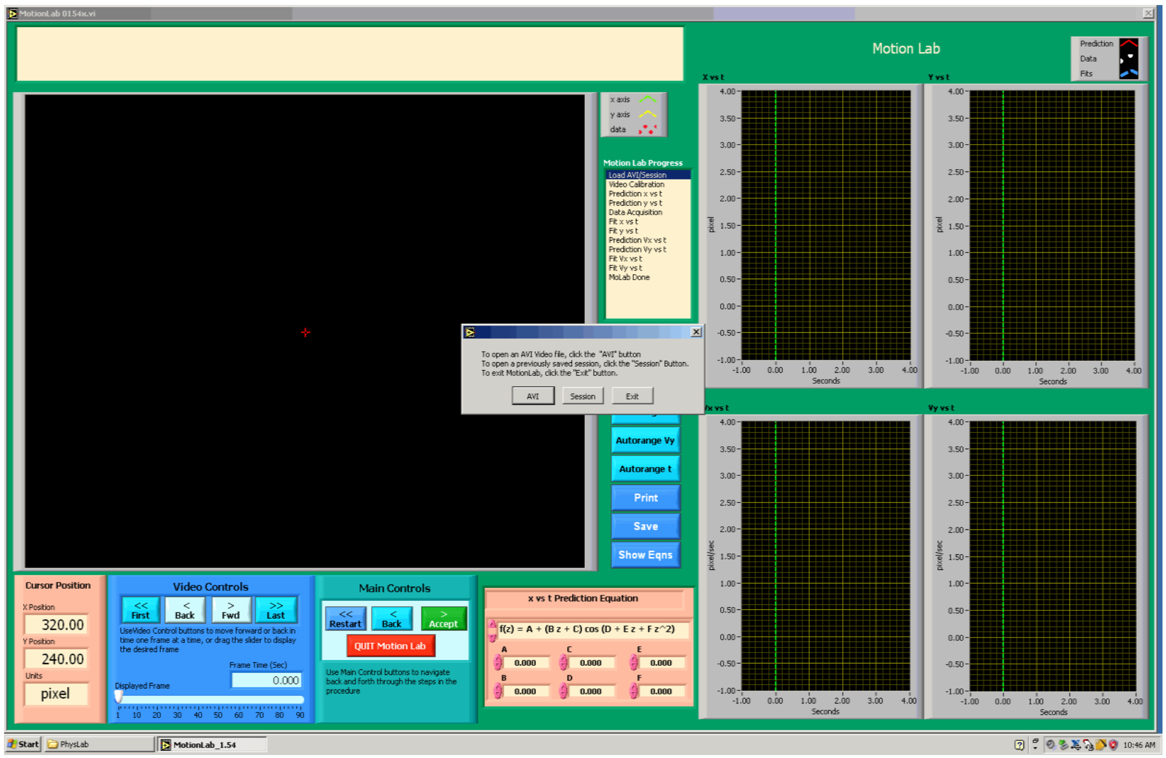
Once you have recorded a satisfactory video, save it by pressing the *Save Video* button. You will see a *Save* window, as shown on the next page.

To avoid cluttering the computer, you will only be able to save your video in the *Lab Data* folder located on the desktop. In the *File name* box, you should enter the location of the folder in which you wish to save your video followed by the name that you wish to give to your video. This name should be descriptive enough to be useful to you later (see the picture for an example).

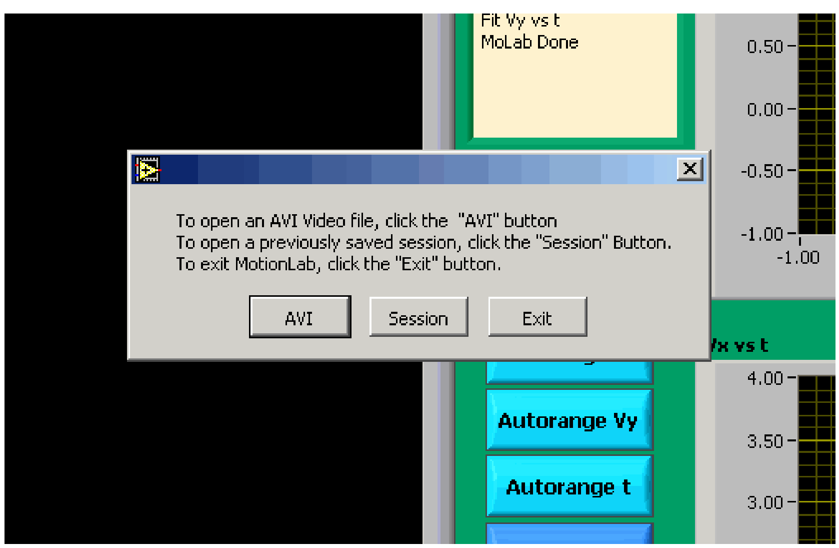


ANALYSIS BASICS

Open the video analysis application by clicking the icon labeled *MotionLab* on the desktop. You should now take a moment to identify several elements of the program. As a whole the application looks complex, but it is easy to use once broken down.

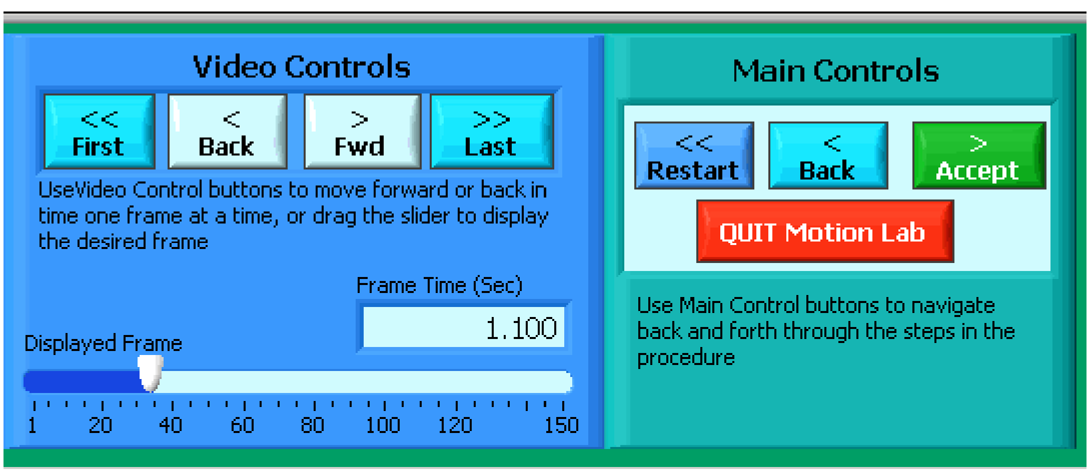


The application will prompt you to open a movie (or previously saved session) as shown below.

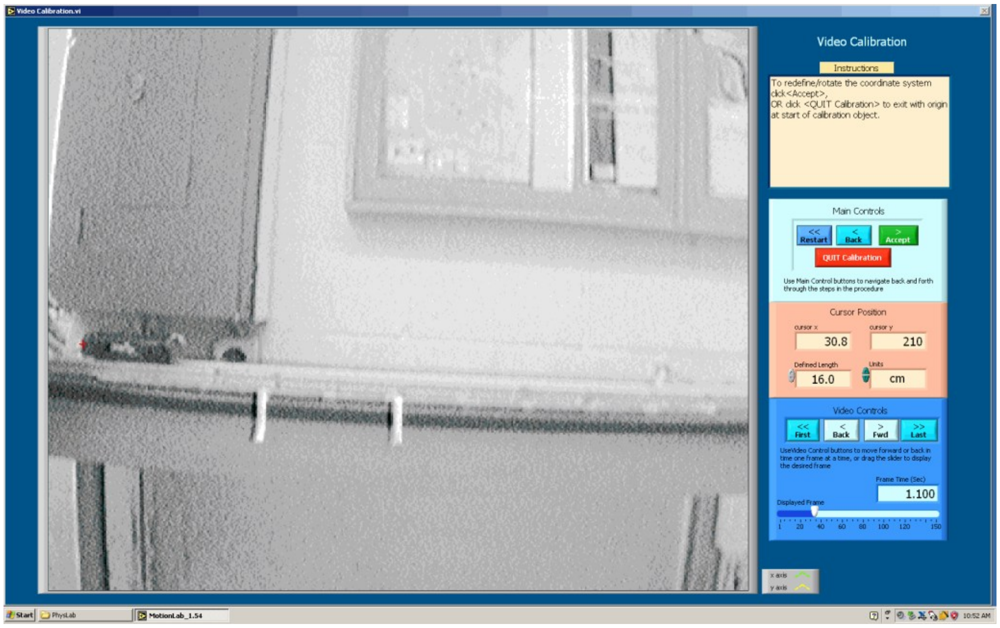


The upper-left corner displays a dialog box with instructions for each step during your movie analysis. To the right of the video screen is a progress indicator. It will highlight which step you are currently performing.

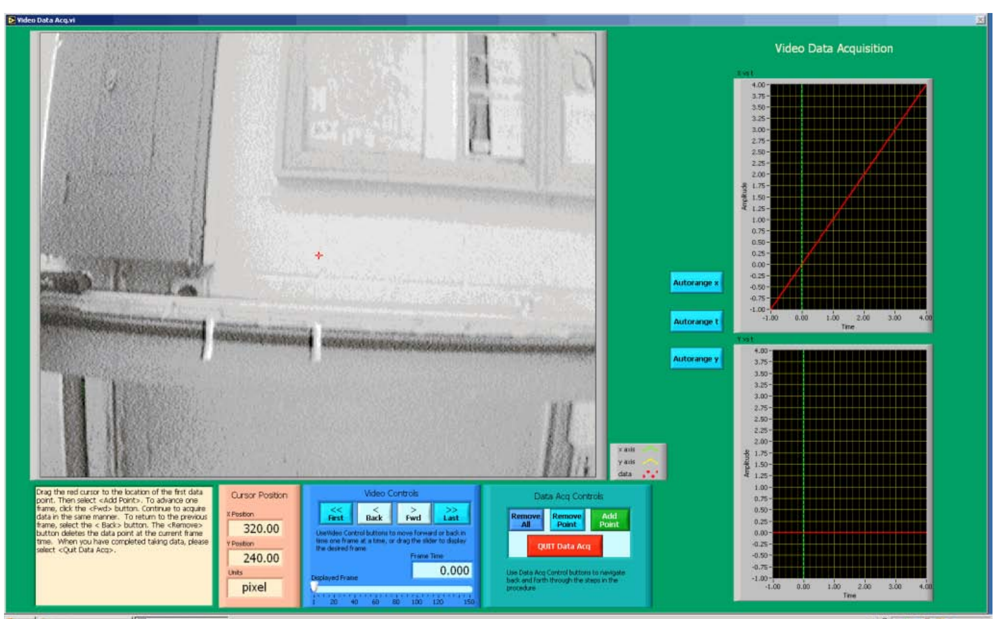
Below the video display is the Video Controls for moving within your AVI movie. The slider bar indicating the displayed frame can also be used to move within the movie. Directly to the right of the Video Controls is the Main Controls. The Main Control box is your primary session control. Use the Main Control buttons to navigate back and forth through the steps shown in the progress box. The red Quit Motion Lab button closes the program.



During the course of using MotionLab, bigger video screens pop up to allow you to calibrate your movie and take data as accurately as possible. The calibration screen is shown below. The calibration screen has the instructions box to the right of the video with the Main Controls and Video Controls directly below. The calibration screen automatically opens once an AVI movie has been loaded.

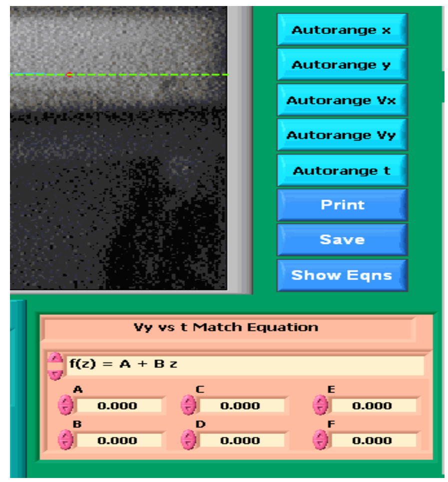


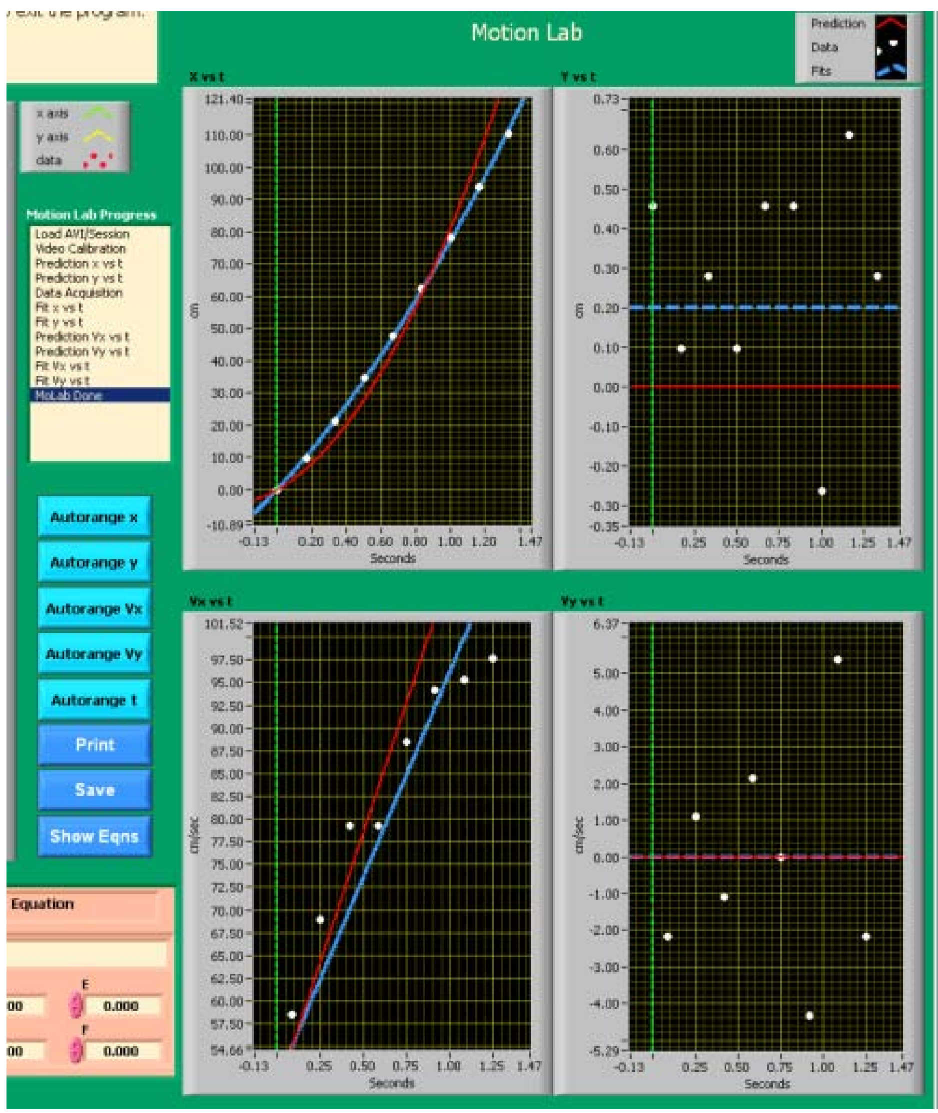
The data acquisition screen is shown below. To get to the data acquisition screen you need to first enter predictions (the progress indicator will display the current step). More will be said about predictions in a bit. The data acquisition screen has the same instructions box and video controls, along with a data acquisition control box. The data acquisition controls allow you to take and remove data points. The red *Quit Data Acq* button exits the data collection subroutine and returns to the main screen once your data has been collected. The red cursor will be moved around to take position data from each frame using your mouse.



Be careful not to quit without printing and saving your data! You will have to go back and analyze the data again if you fail to select *Print Results* before selecting *Quit.*

There are just a few more items to point out before getting into calibration, making predictions, taking data and matching your data in more detail. To the right the picture shows the equation box for entering predictions and matching data. Directly above this and below the progress indicator you have controls for setting the range of the graph data and controls for printing and saving. The graphs that display your collected data are shown below. Your predictions are displayed with red lines; fits are displayed with blue lines





CALIBRATION

While the computer is a very handy tool, it is not smart enough to identify objects or the sizes of those objects in the videos that you take and analyze. For this reason, you will need to enter this information into the computer. If you are not careful in the calibration process, your analysis will not make any sense.

After you open the video that you wish to analyze the calibration screen will open automatically. Advance the video to a frame where the first data point will be taken. The time stamp of this frame will be used as the initial time. To advance the video to where you want time $t = 0$ to be, you need to use the video control buttons. This action is equivalent to starting a stopwatch.

Practice with each button until you are proficient with its use. When you are ready to continue with the calibration, locate the object you wish to use to calibrate the size of the video. The best object to use is the object whose motion you are analyzing, but sometimes this is not easy. If you cannot use the object whose motion you are analyzing, you must do your best to use an object that is in the plane of motion of your object being analyzed.

Follow the direction in the *Instructions* box and define the length of an object that you have measured for the computer. Once this is completed, input the scale length with proper units. Read the directions in the Instructions box carefully.

Lastly, decide if you want to rotate your coordinate axes. If you choose not to rotate the axes, the computer will use the first calibration point as the origin with positive x to the right and positive y up. If you choose to rotate your axis, follow the directions in the Instructions box carefully. Your chosen axes will appear on the screen once the process is complete. This option may also be used to reposition the origin of the coordinate system, should you require it.

Once you have completed this process, select *Quit Calibration*.

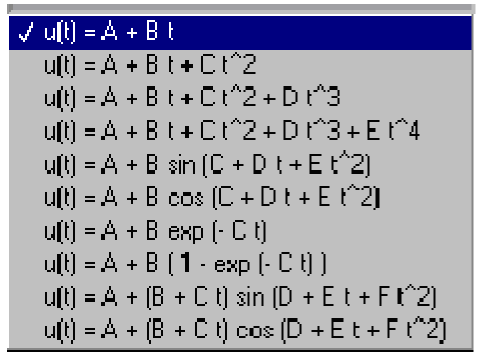
ANALYSIS PREDICTIONS

This video analysis relies on your graphical skills to interpret the data from the videos. Before doing your analysis, you should be familiar with both Appendix C: Graphing and Appendix B: Uncertainties.

Before analyzing the data, enter your prediction of how you expect the data to behave. This pattern of making predictions before obtaining results is the only reliable way to take data. How else can you know if something has gone wrong? It is also a good way to make sure you have learned something, but only if you stop to think about the discrepancies or similarities between your prediction and the results.

In order to enter your prediction into the computer, you first need to decide on your coordinate axes, origin, and scale (units) for your motion. Record these in your lab journal.

Next you will need to select the generic equation, $u(t)$, which describes the graph you expect for the motion along your x-axis seen in your video. You must choose the appropriate function that matches the predicted curve. The analysis program is equipped with several equations, which are accessible using the pull-down menu on the equation line. The available equations are shown to the right.



You can change the equation to one you would like to use by clicking on the arrows to the left of the equation

After selecting your generic equation, you next need to enter your best approximation for the parameters A and B and C and D where you need them.

If you took good notes of these values during the filming of your video, inputting these values should be straightforward. You will also need to decide on the units for these constants at this time.

Once you are satisfied that the equation you selected for your motion and the values of the constants are correct, click *Accept* in the *Main Controls* box. Your prediction equation will then show up on the graph on the computer screen. If you wish to change your prediction simply repeat the above procedure. Repeat this procedure for the y direction.

DATA COLLECTION

To collect data, you first need to identify a very specific point on the object whose motion you are analyzing. Next move the cursor over this point and click the green *Add Point* button in data acquisition control box. The computer records this position and time. The computer will automatically advance the video to the next frame leaving a mark on the point you have just selected. Then move the cursor back to the same place on the object and click the Add Point button again. So long as you always use the same point on the object, you will get reliable data from your analysis. This process is not always so easy, especially if the object is moving rapidly. The data will automatically appear on the graph on your computer screen each time you accept a data point. If you don't see the data on the graph, you will need to change the scale of the axes. If you are satisfied with your data, choose *Quit Data Acq*.

FITTING YOUR DATA

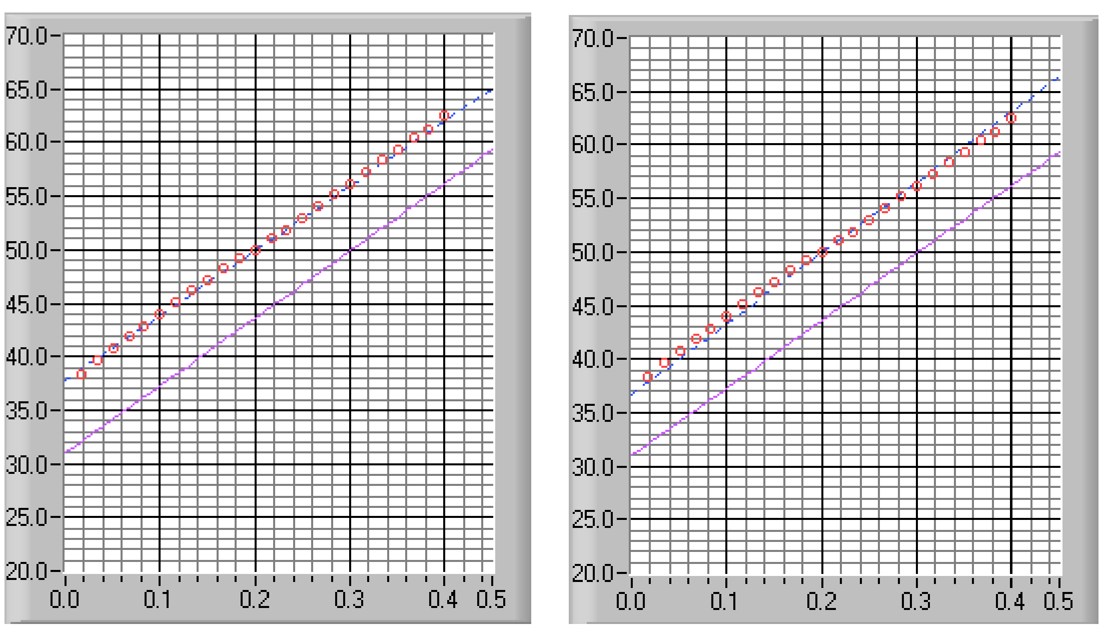
Deciding which equation best represents your data is the most important part of your data analysis. The actual mechanics of choosing the equation and constants is similar to what you did for your predictions.

First you must find your data on your graphs. Usually, you can find your full data set by using the *Autorange* buttons to the left of the graphs.

Second, after you find your data, you need to determine the best possible equation to describe this data. After you have decided on the appropriate equation, you need to determine the constants of this equation so that it best fits the data. Although this can be done by trial and error, it is much more efficient to think of how the behavior of the equation you have chosen depends on each parameter. Calculus can be a great help here.

Lastly, you need to estimate the uncertainty in your fit by deciding the range of other lines that **could** also fit your data. This method of estimating your uncertainty is described in Appendix C. Slightly changing the values for each constant in turn will allow you to do this quickly. For example, the x-motion plots below show both the predicted line (down) and two other lines that also fit the data (near the circles).

After you have found the uncertainties in your constants, return to your best-fit line and use it as your fit by selecting *Accept x- (or y-) fit* in the *Program Controls* panel.



LAST WORDS

These directions are not meant to be exhaustive. You will discover more features of the video analysis program as you use it. Be sure to record these features in your lab journal.

REFERENCE GUIDE FOR ULTR@ VNC

Ultr@ VNC is a computer program in the physics lab rooms that gives you the power to observe student computer screens and control a student's computer remotely via your keyboard and mouse. It is particularly useful for giving instructions about a program or displaying students' lab data.

To access Ultr@ VNC, log in to a lab computer with a TA username and password, i.e., your University-issued x500 credentials. If you would potentially like to broadcast a screen using the digital projector, the computer must be the instructor computer.

Access the program *UltraVNC Viewer* in the *UltraVNC* directory under *All Programs* in the *Start* menu. See Figure 1. You can also access the program from the file manager via the path `C:\Program Files\UltraVNC\vncviewer.exe`.

A pop-up window should appear, requesting the name of the display host. See Figure 2. In the *VNC Server* drop-down field, type the number of the student's computer that you want to observe. The numbers are printed on each computer and should be in the format SPA-PH-##-##.

If you want to change connection options, click the *Options* button. Another pop-up window will appear; see Figure 3. *Auto select best settings* is the default.

Click *Connect* to begin viewing the selected desktop. An authentication pop-up window will appear, requesting a username and password. Type in `vnc` for the former and `labvnc` for the latter. Click *Log On*.

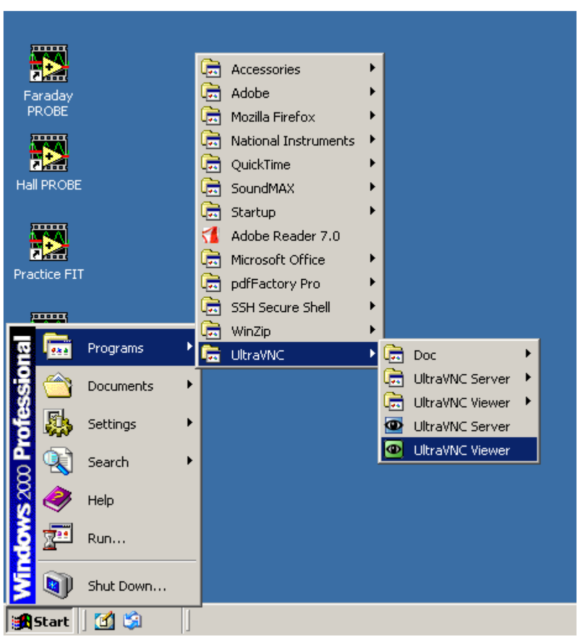


Figure 1. Opening the Ultr@ VNC viewer program from the Start menu.

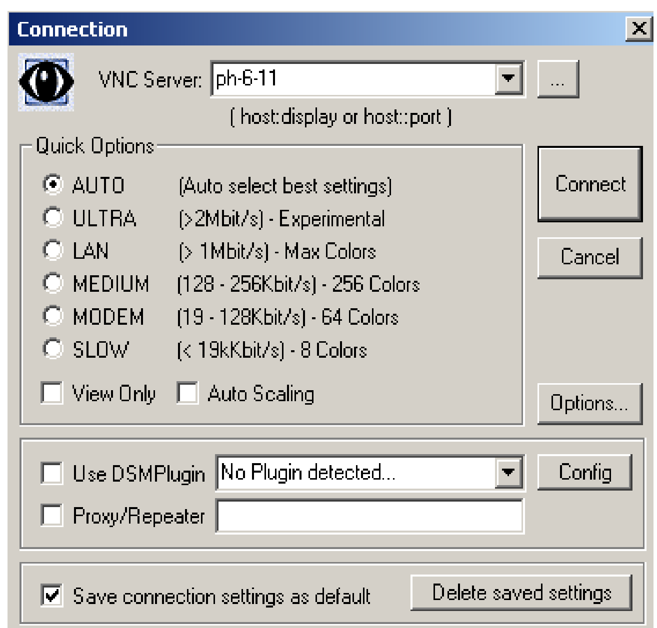


Figure 2. The Connection window.

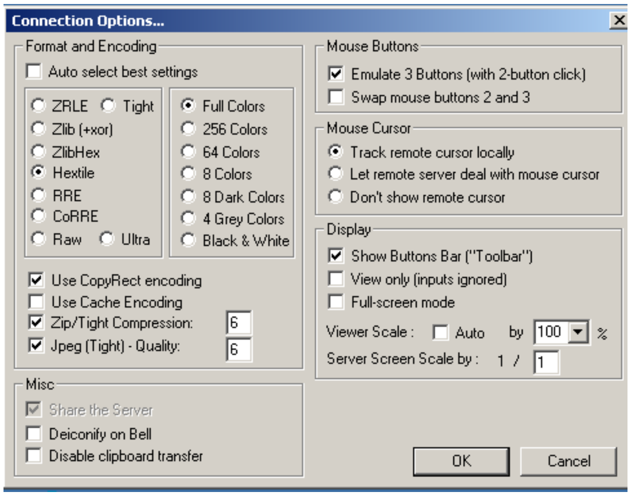


Figure 5. The extended connection options window.

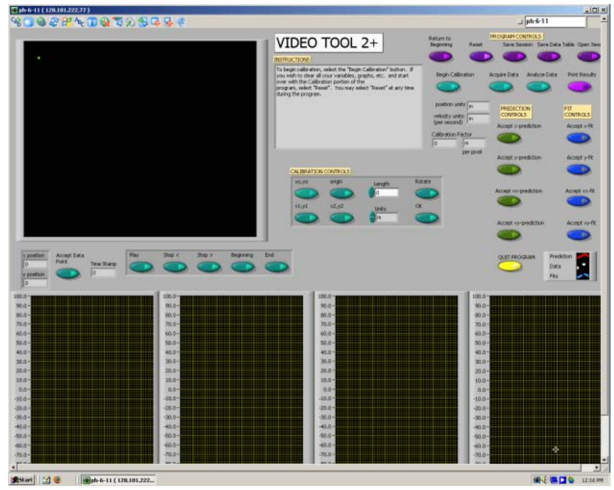


Figure 4. A student screen displayed using VNC. Note the VNC toolbar in the upper-left corner.

A view of a student screen is depicted in Figure 4. The VNC window has controls along its edges that allow you interface with the host, control the connection, scroll the view around the host's desktop, and so forth. Use the toolbar buttons, seen in Figure 5, to control Ultr@ VNC. Most buttons are self-explanatory, but selected descriptions are given below.

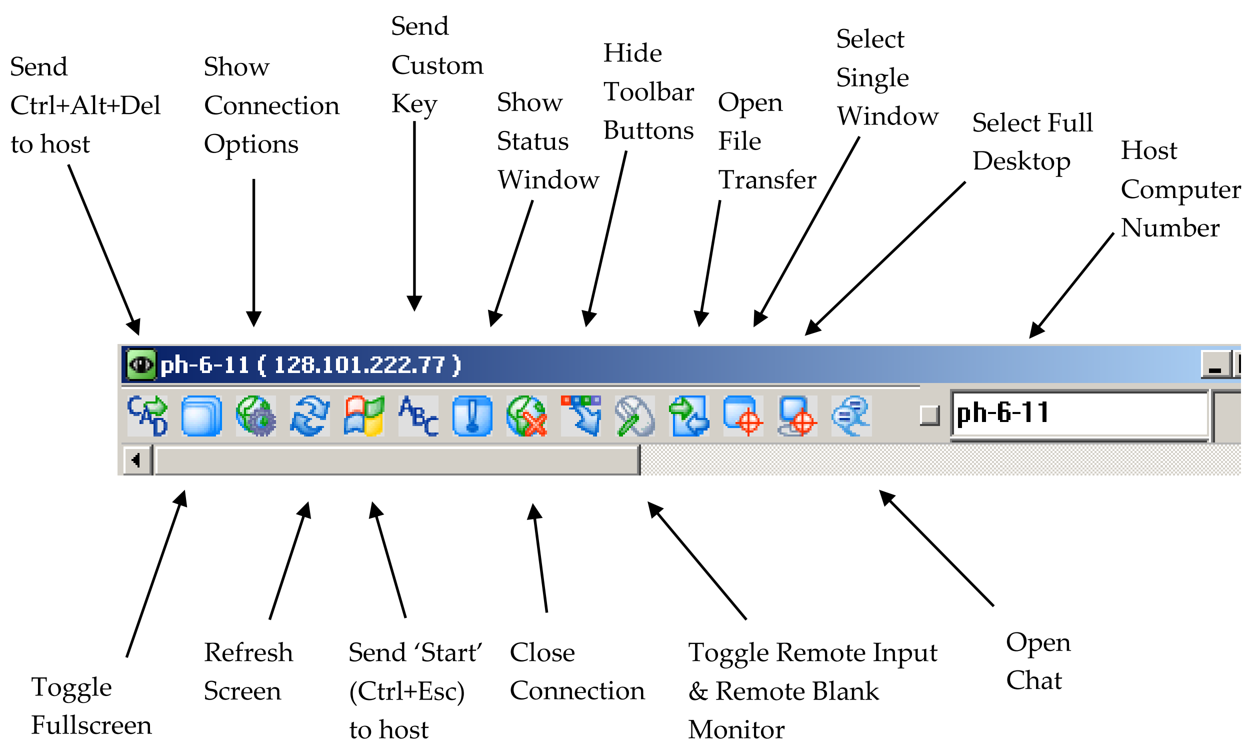


Figure 3. The Ultr@ VNC viewer toolbar.

- *Send Ctrl+Alt+Del to host* will bring up the physics logout window on the student's computer.
- *Send 'Start' (Ctrl+Esc) to host* will depress the start button on the student's computer, giving you the power to access programs, etc. from the host computer.
- *Show Connection Options* will display the same pop-up window that is available from the Options button of the initial Connection window (Figure 3).
- *Toggle Remote Input & Remote Blank Monitor* gives total control to the instructor by disabling the student's computer mouse.
- *Select Single Window* gives you the option to select and view one window that is open on a student's screen, providing multiple windows are opened at the same time. When this toolbar button is depressed, a crosshair appears and you can use this to click on the window to be viewed. Any remaining windows are blacked out. To return to the full view, click the *Select Full Desktop* toolbar button.

It is possible to display multiple student screens simultaneously, but you must reopen the Ultr@ VNC program each time and resize the windows (or only view one screen at a time).

To exit Ultr@ VNC, click *Close Connection*.

For more information, the software developers' website is http://www.uvnc.com.