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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.

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 AT THE BEGINNING OF LAB!

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 topics are not synchronized, as well as about any other issues 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. You should **resist** if the professor asks you to introduce a new topic in lab by giving students a lecture! Another option would be 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 easer 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. Even thought the Prediction comes first in the lab manual, they should do the Warm-up questions before the Prediction.

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.

4. Tell the students what resources are available to them and encourage going to the tutor room 230 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 primary 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

1. If there is any bad, broken, or erratic equipment, **use the problem report form** located on any lab computer desktop to **immediately notify the lab coordinator**. This form will send an 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. **Make a note on the clipboard about it** or on the blackboard to inform the next TA of the problem, and that a problem report form has already been submitted.

   Remove any broken equipment from the front lab table immediately: students are less respectful towards equipment that they don't see working well.

2. 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 camera and shut down the computer.
   - Never turn off the power to a computer without shutting it down first.

3. If there is no video image in the *Video Camera* window, check the following:
   - The camera is turned on and plugged in.
   - The cable is plugged into the back of the camera.
   - The cable is in the "Video In" port on the back of the computer.

4. If the students' data won't print out, check the following:
   - The printer is turned on and has paper.
   - The *Print Results on Close* button was selected in the video analysis program.
   - Open the *Printers* folder from the Control Panel, and double-click the relevant printer. If the document to be printed is not there, then the data should be on its way.
   - When printing out a data table, first go to page setup. Choose the landscape option, and reduce the size to around 75%. Otherwise the data will overlap giving a very confusing table.

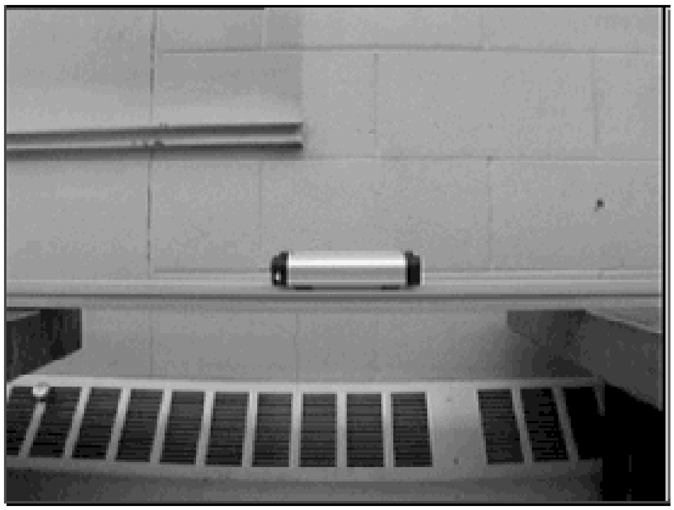
5. Some suggestions about the camera and video analysis program:
   - The computer will skip fewer frames if the background of a given movie is free from clutter.
   - Take a few moments to learn how to focus the camera with the zoom feature. The zoom adjustment is at the end of the lens, while the focus is near the base.
   - 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. (Note that the radiator below the camera level looks curved due to distortion. This is less of a problem with the newer cameras.)
- 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 lens 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:

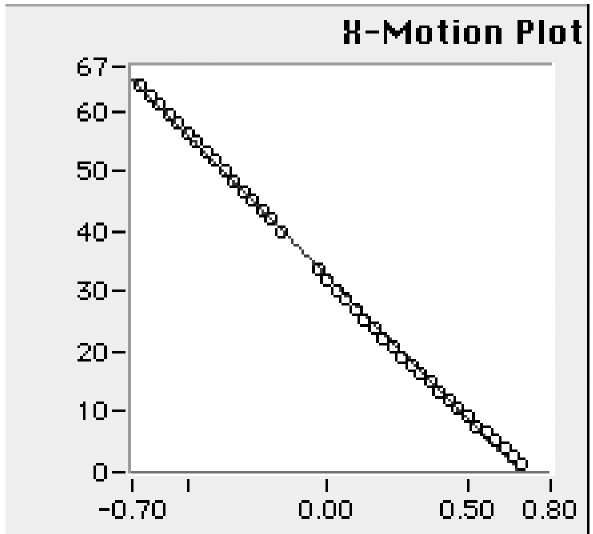
- The camera is not level with the cart's motion. The video is shot from above, which causes the cart's image to be distorted. Notice that the right side of the cart is visibly closer to the camera than the left side. Thus our 2-D picture has a 3-D component for which we cannot account – this will cause 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 movie will also be more likely to skip frames (you want as little useless information in the screen as possible).
- The adjustments on the camera lens 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).

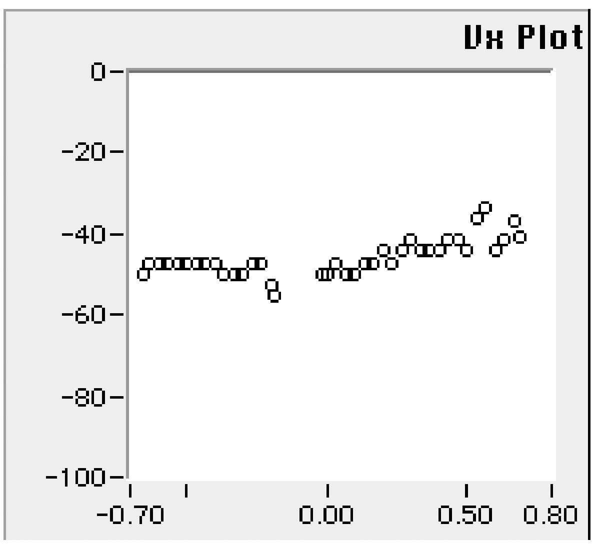
Analysis of our movies

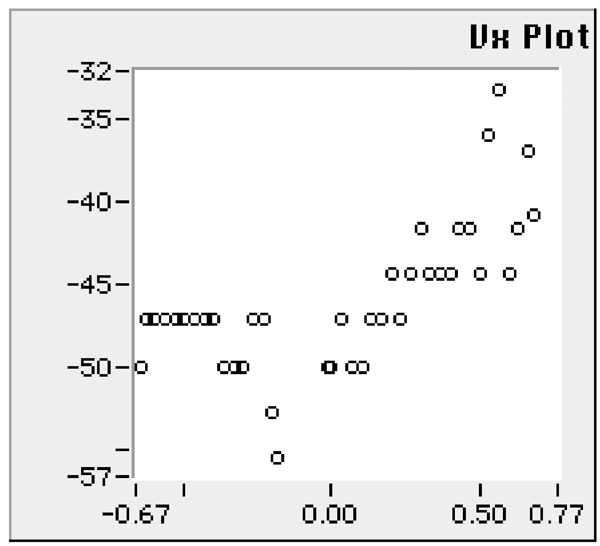
Here we analyze the movies (two frames of which are shown on the previous pages). The motion is that of a cart moving with constant velocity along the track. Although the velocities are different, we can still use the movies to compare what are considered good results with those that are bad.

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.





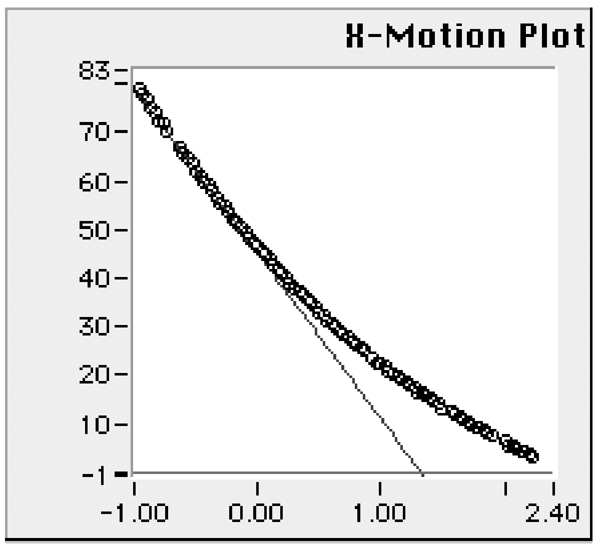


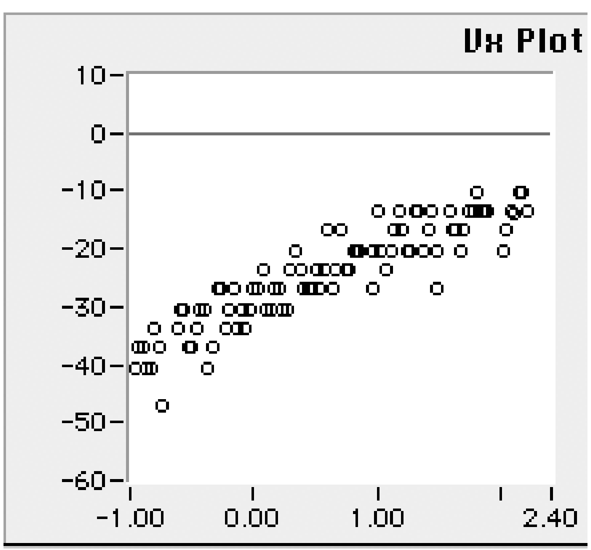
We include two velocity-versus-time graphs for the good movie. In the plot on the left we put in the axis limits ourselves. The plot on the right is "autoscaled." (Both plots are identical except for the y-axis scaling.) We include both graphs to show how "autoscale" may mislead the students into thinking 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.

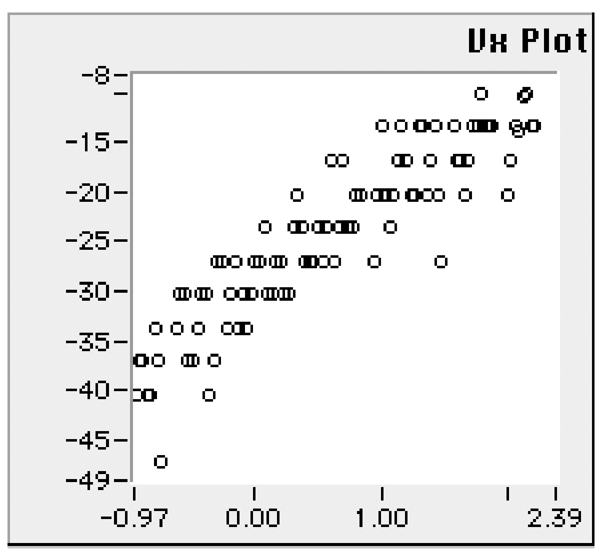
You may have noticed that some of the data points were taken at "negative" time (the horizontal axis is the time axis). This is due to the fact that we forwarded the movie to the frame in which the cart was at the center of the screen to do our calibration. We then reversed the movie so we could start 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.

The computer didn't skip as many frames in the bad movie as in the good movie. This is most likely because the screen was so washed out, it couldn't see the detail (the more detail, the more likely the computer is to skip frames).

USING THIS INSTRUCTOR'S GUIDE

This instructor's guide is designed to help you help your students, make sure you:

1. Don't rely on it too much. It is only a guide, not a substitute, for preparation. Make sure you prepare to teach the lab as if you didn't have this manual.
2. **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 section for each lab.** Return these forms to Sean Albiston or one of the mentor TAs. You can also e-mail the information to Sean directly at lab@physics.umn.edu

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 with stars 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 0: Determining an Equation from a Graph

This Lab, and the PracticeFIT program, will familiarize students with matching equations to graphs. Many students have trouble with this. It should be useful to every student at the beginning of the semester, since they will find equations to match graphs nearly every time they use the computer. The program allows students to try several graphs in a short time.

Targeted use of the PracticeFIT program could be useful to particular students later in the semester, to help them learn about:

- manipulating axis bounds to "see" data points;
- dependence of graph shape on function type;
- dependence of graph shape on the constant parameters in different types of functions.

You may have students try particular "Mystery Functions" to work on specific difficulties. The "Mystery Functions" are described below:

Mystery Function	Specification in PracticeFIT 2+ Fall '05	COMMENT / Details
1	u(t) = [-5,5] + [-2.5,2.5]t	SIMPLEST / Linear; u(t) = A + Bt; A is random integer in [-5,5]; B is random half-integer in [-2.5,2.5]
2	u(t) = [-24.0,15.0;0;15.0,24.0] + [-5.0,5.0]t	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	u(t) = [-15.0,15.0] + [-5.0,5.0]t^2	PARABOLA, SYMMETRICAL AROUND X=0
4	u(t) = [-15.0,15.0] + [-5.0,5.0]t + [-5.0,5.0]t^2	PARABOLA
5	u(t) = [-15.0,15.0] + [0,6.0]sin([0,3pi]t)	SIN FUNCTION
6	u(t) = [-15.0,15.0] + [0,6.0]sin([0,2pi] + [0,3pi]t)	SIN FUNCTION WITH PHASE SHIFT
7	u(t) = [-15.0,15.0] + [-5.0,5.0]exp ([0,3.0] t)	EXPONENTIAL
8	Function=[0,7]; A=[-5.0,5.0]; B=[-5.0,5.0]; C=[-5.0,5.0]	RANDOM FUNCTION, UP TO 3 NON-ZERO PARAMETERS
9	Function=[0,7]; A=[-5.0,5.0]; B=[-5.0,5.0]; C=[-5.0,5.0]; D=[-5.0,5.0]	RANDOM FUNCTION, UP TO 4 NON-ZERO PARAMETERS
10	Function=[0,7]; A=[-5.0,5.0]; B=[-5.0,5.0]; C=[-5.0,5.0]; D=[-5.0,5.0]; E=[-5.0,5.0]	RANDOM FUNCTION, UP TO 5 NON-ZERO PARAMETERS

Laboratory I: One-Dimensional Motion

Laboratory 1 has six problems. 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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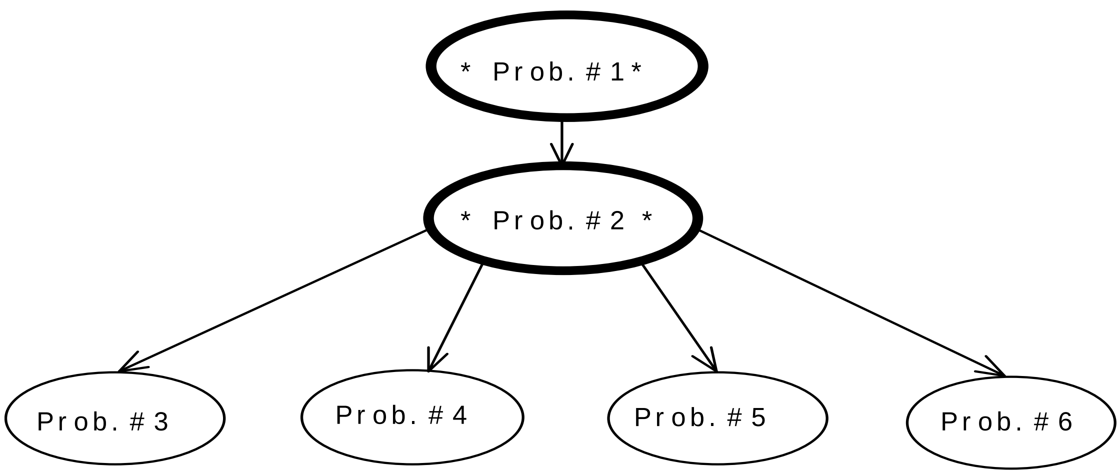


(For an explanation of the elements of the above flow chart, please refer to the bottom of page 1 of Introduction.)

General Teaching Tips:

- Every group needs to do the first and second problems (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.

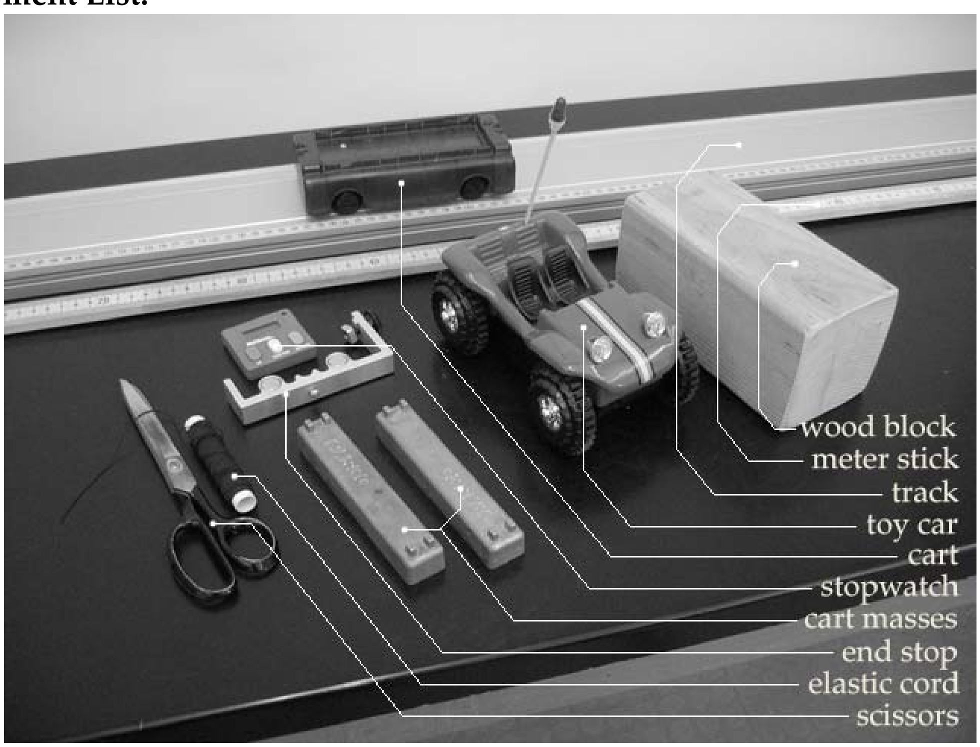
By the end of this lab students should be able to:

- 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.

Things to check out before entering a lab with students: (Takes about 15 minutes)

- 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.

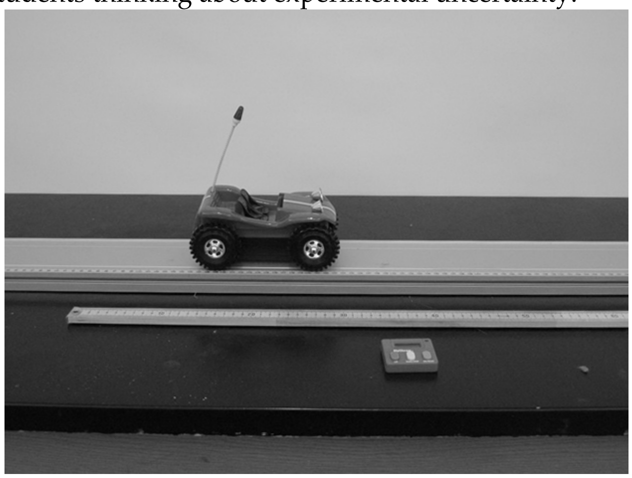
Equipment List:



Problem #1: Constant Velocity Motion

Purpose:

- To introduce students briefly to the need for experimental technique, by analyzing motion in one dimension.
- To get familiar with the camera and video analysis software 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.



Teaching Tips:

1. 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. This is best to get out of the way during the first week of class after introductions and diagnostic testing
2. 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. Problem #1 continues this general introduction to the lab format.
3. Students become overwhelmed by the computer and forget the purpose of this lab. You will need to remind them that they are trying to describe the motion of a car moving with constant velocity.
4. You should suggest to your students that they should investigate the edges of the cameras image. This is their chance to understand if the camera has limitations. If they do not find limitations, they will not be able to claim difficulties or errors coming from the equipment later in the semester.
5. 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.

6. 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.
7. 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. If you have time, you can ask for each group member to make a movie enforcing everyone in the group to operate the computer.

Difficulties and Alternative Conceptions:

Students have difficulty connecting graphs with physics and connecting graphs with the real world. For example, just because the position vs. time graph slopes upwards does not mean that the cart is moving on an upward slope. Since the motion here is simple, it should be easy to identify these students and help them. Emphasize that the velocity they measure with the stopwatch is the velocity they should use in their prediction. They should understand why the average velocity of the cart equals its instantaneous velocity in this case. Make sure they understand the meaning of a positive or negative slope of the position vs. time graph. Also make sure they know where the origin of their graph is and what the origin means.

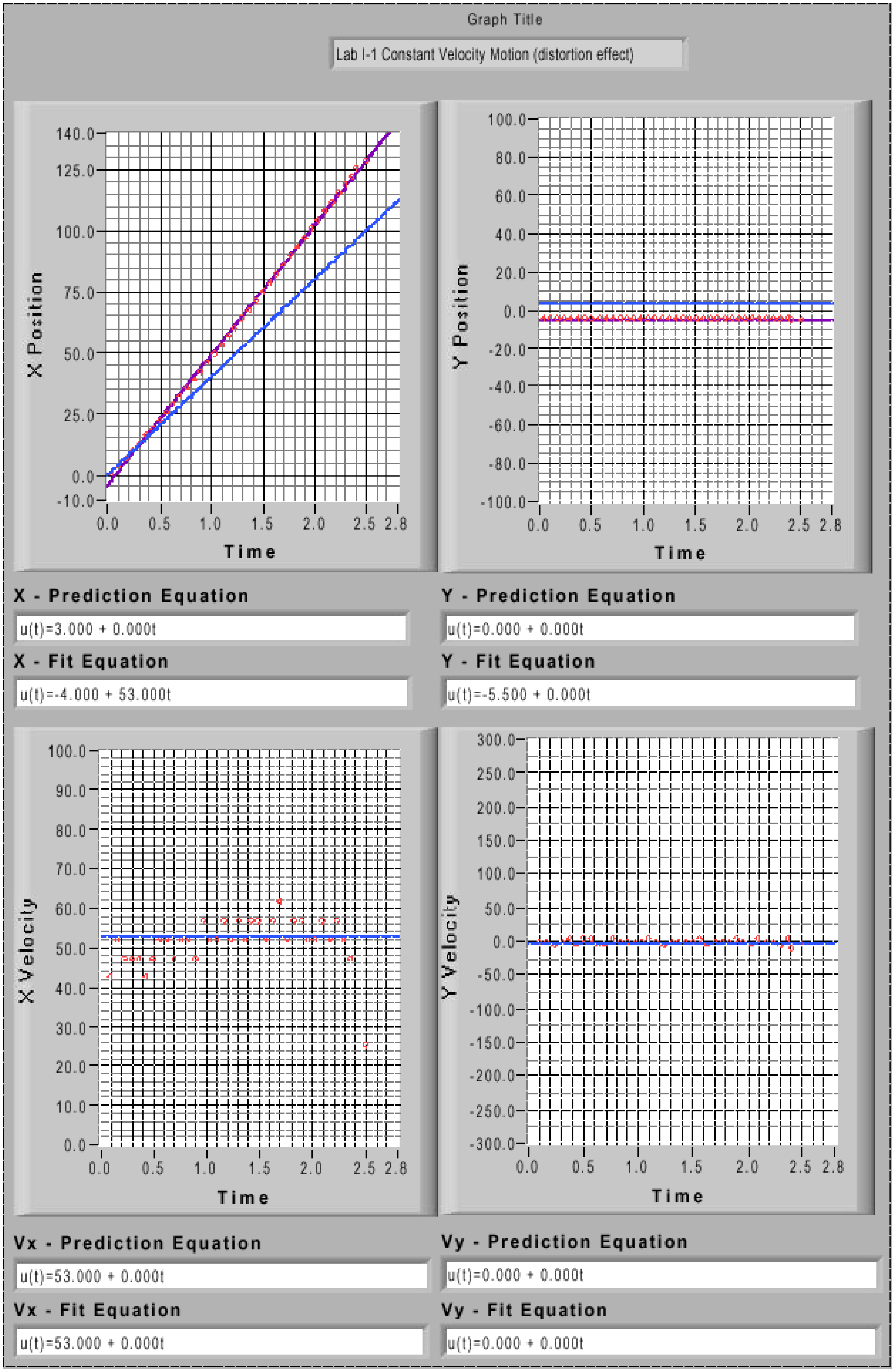
Prediction and Warm up questions:

The prediction and warm up questions are straightforward.

(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 is about 53cm/s.


Graph Title
Lab I-1 Constant Velocity Motion (distortion effect)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=3.000 + 0.000t
X - Fit Equation
u(t)=-4.000 + 53.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-5.500 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=53.000 + 0.000t
Vx - Fit Equation
u(t)=53.000 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

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 $\boxed{v_{avg} \neq v_{inst}}$ but $\boxed{a_{avg} = a_{inst.}}$ because the acceleration is constant.

Teaching Tips:

1. 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.
2. 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).
3. (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:

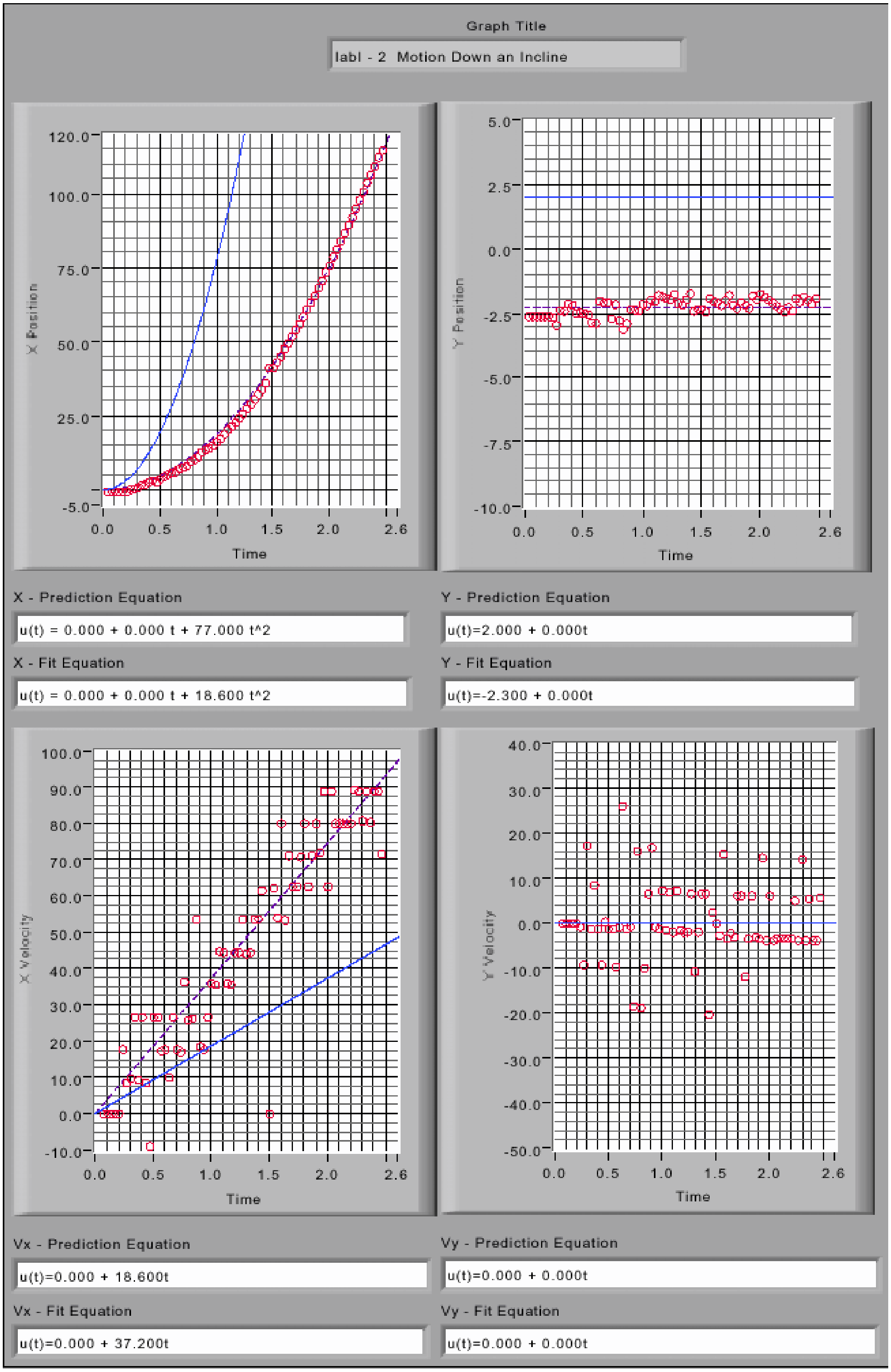
Acceleration and velocity are hotbeds of alternative conception. In this problem we are trying to get the students to distinguish between velocity and acceleration, between position and displacement, and between average and instantaneous quantities.

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.

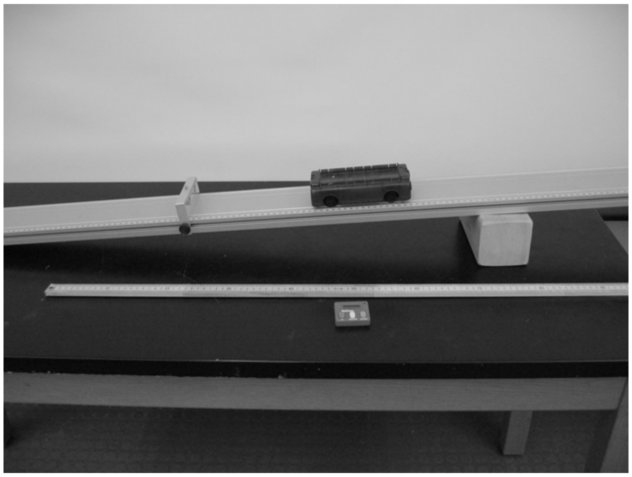
Sample Data:

Inclined angle: $\sin^{-1}(8.7/220.5)$; Acceleration: $a=37.2 cm/s^2$.


Graph Title
labl - 2 Motion Down an Incline
X Position
Time
Y Position
X - Prediction Equation
u(t) = 0.000 + 0.000 t + 77.000 t^2
X - Fit Equation
u(t) = 0.000 + 0.000 t + 18.600 t^2
Y - Prediction Equation
u(t)=2.000 + 0.000t
Y - Fit Equation
u(t)=-2.300 + 0.000t
X Velocity
Y Velocity
Vx - Prediction Equation
u(t)=0.000 + 18.600t
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

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.

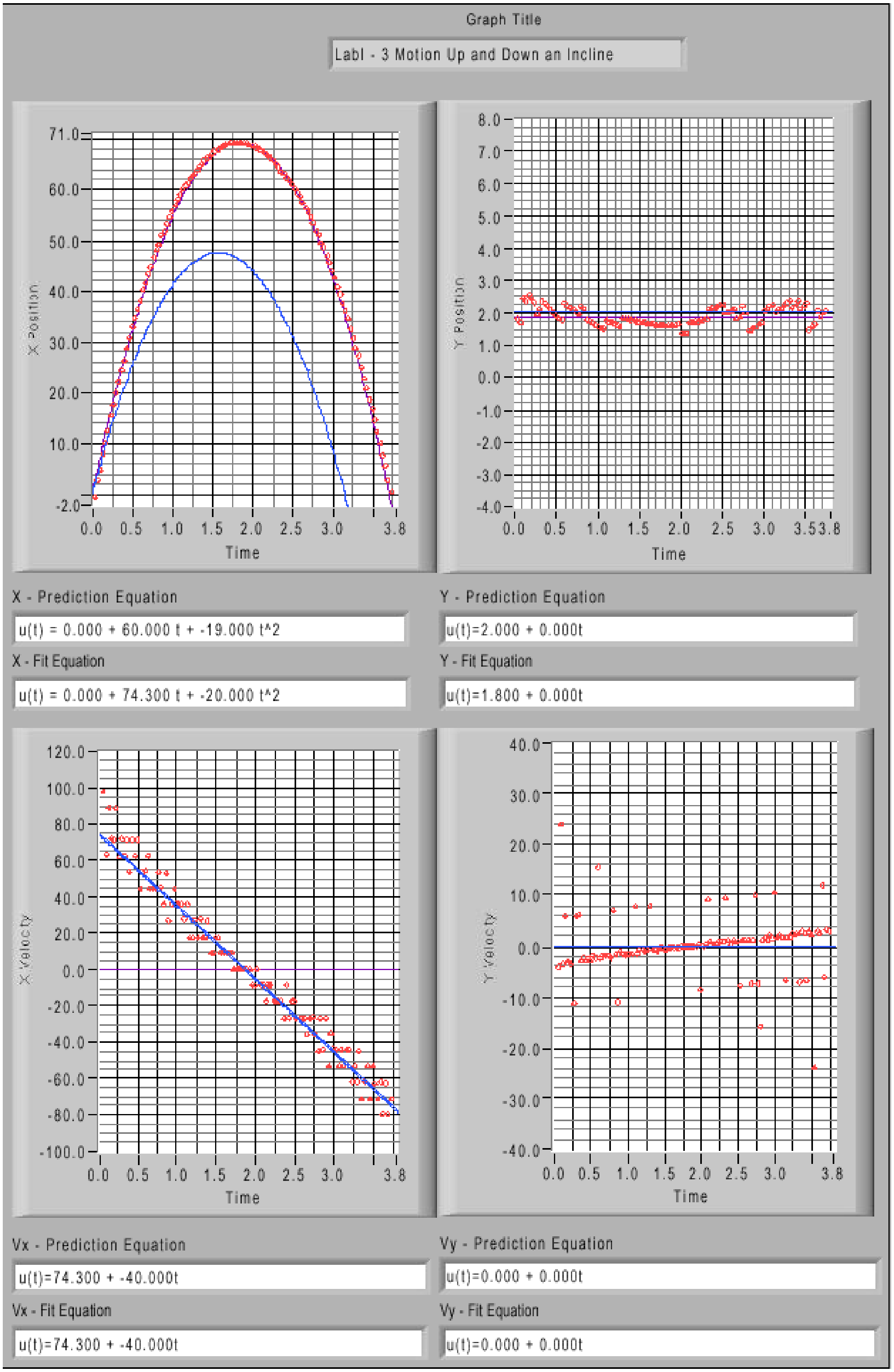


Teaching Tips:
1. Have the students compare the results of the motion of the cart up and down the incline. Watch for students who think the acceleration changes direction for the two cases. The graphical analysis is very useful here if the students understand the meaning of the slope of the velocity 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.

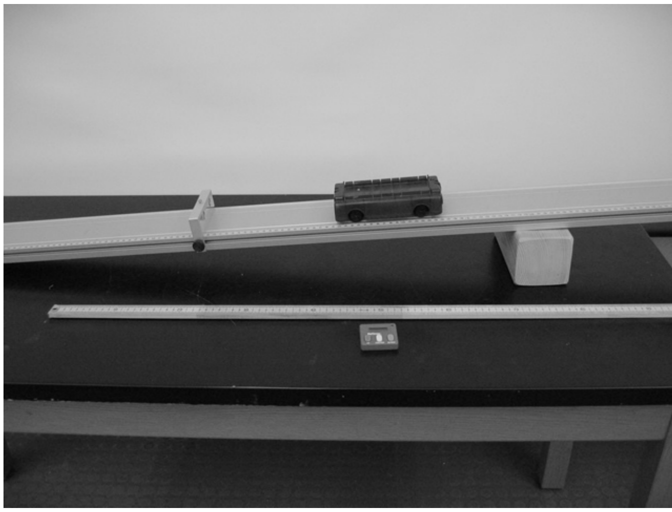
Sample Data:
Inclined angle: $\sin^{-1}(8.7/220.5)$;
Acceleration: $a = 40 cm/s^2$.


Graph Title
Labl - 3 Motion Up and Down an Incline
X Position
Time
Y Position
X - Prediction Equation
u(t) = 0.000 + 60.000 t + -19.000 t^2
X - Fit Equation
u(t) = 0.000 + 74.300 t + -20.000 t^2
Y - Prediction Equation
u(t)=2.000 + 0.000t
Y - Fit Equation
u(t)=1.800 + 0.000t
X Velocity
Y Velocity
Vx - Prediction Equation
u(t)=74.300 + -40.000t
Vx - Fit Equation
u(t)=74.300 + -40.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

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.



Teaching Tips:

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

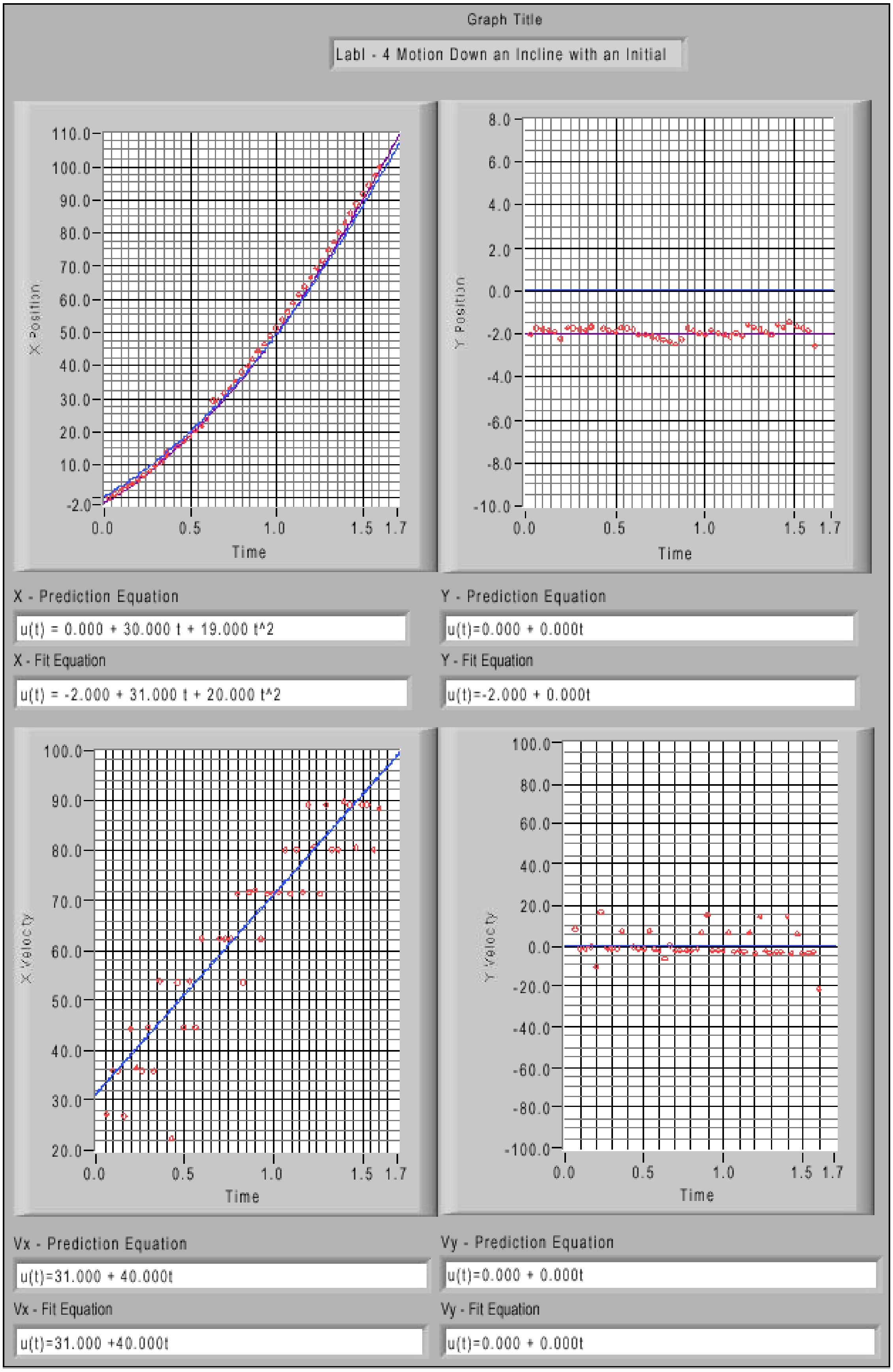
Difficulties and Alternative Conceptions:

The alternative conception here is a faster cart will have a larger acceleration. Another is that the direction of the cart's acceleration is 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).

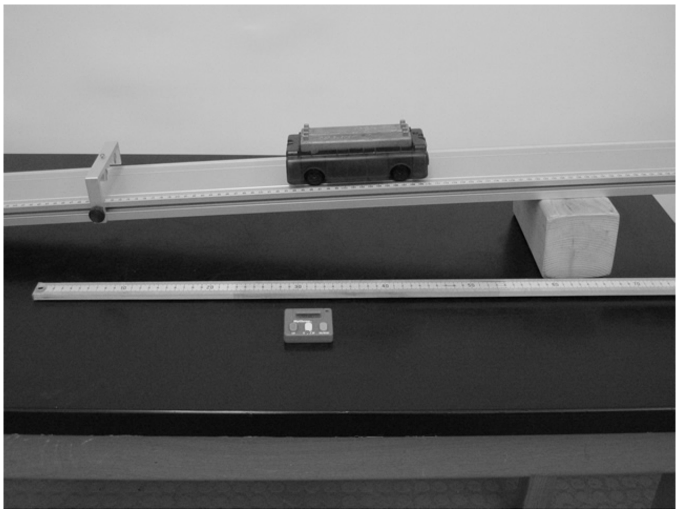
Sample Data: Inclined angle: $\sin^{-1}(8.7/220.5)$;
Initial velocity: V_0=31cm/s;
Acceleration: a=40cm/s^2.


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

Problem #5: Mass and Motion Down an Incline

Purpose:

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



Teaching Tips:

1. 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.
2. 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.
3. 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.

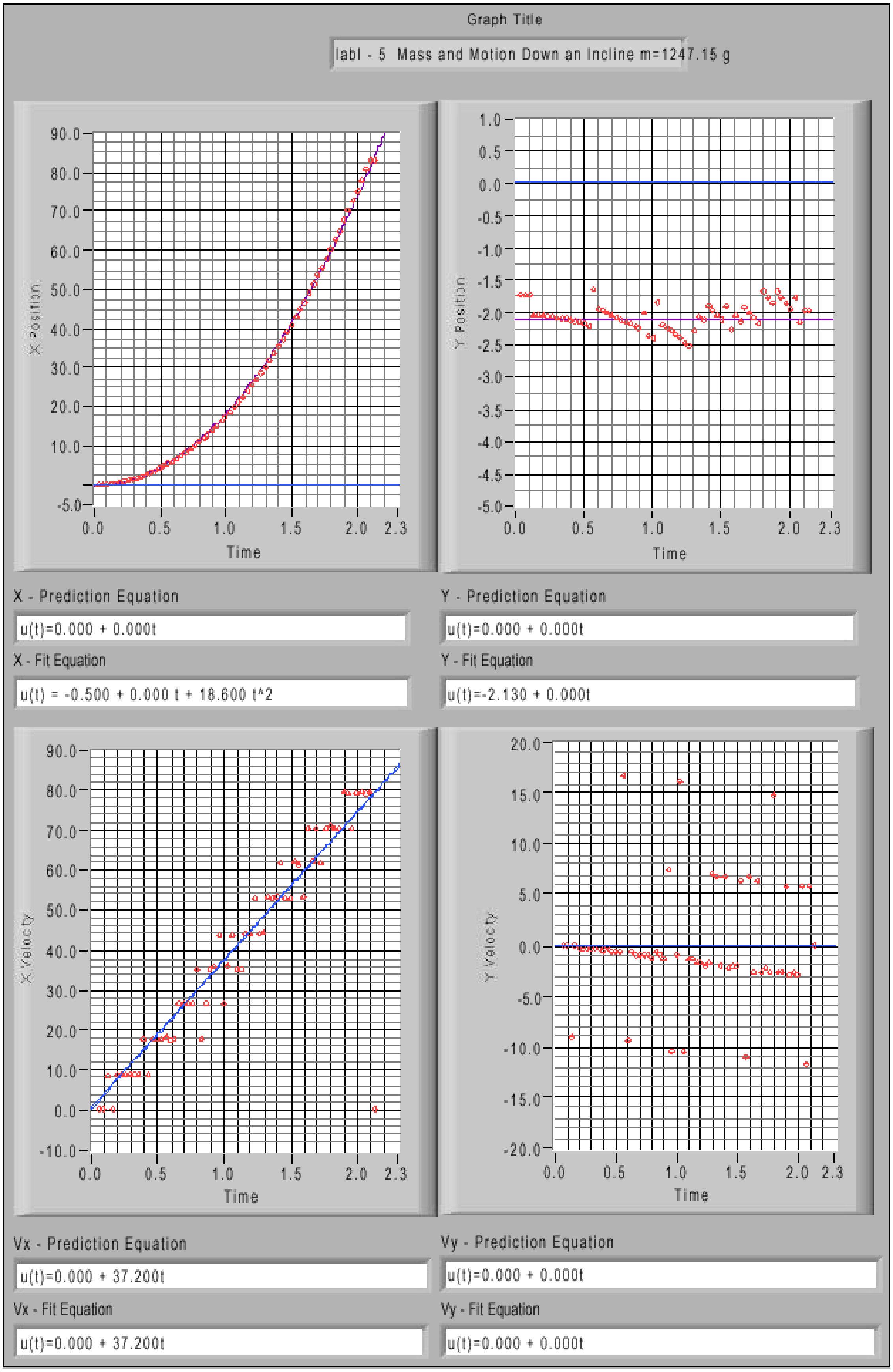
This lab is also not as structured as the previous ones, so if you have a good group, this might be an appropriate problem for them.

Prediction and Warm up questions:

Acceleration is independent of mass.

Sample Data:

Inclined angle: $\text{Sin}^{-1}(8.7/220.5)$;
Case 1 (see Data of problem #2):
Mass of cart 251.65 g
Acceleration 37.2 cm/s^2
Case 2:
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

Problem #6: Motion on a Level Surface with an Elastic Cord

Purpose:

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

Teaching Tips:

1. Be sure the students recognize that $a_{avg} \neq a_{inst}$, in this case.
2. This problem is good for those students who understand acceleration 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.
3. 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.

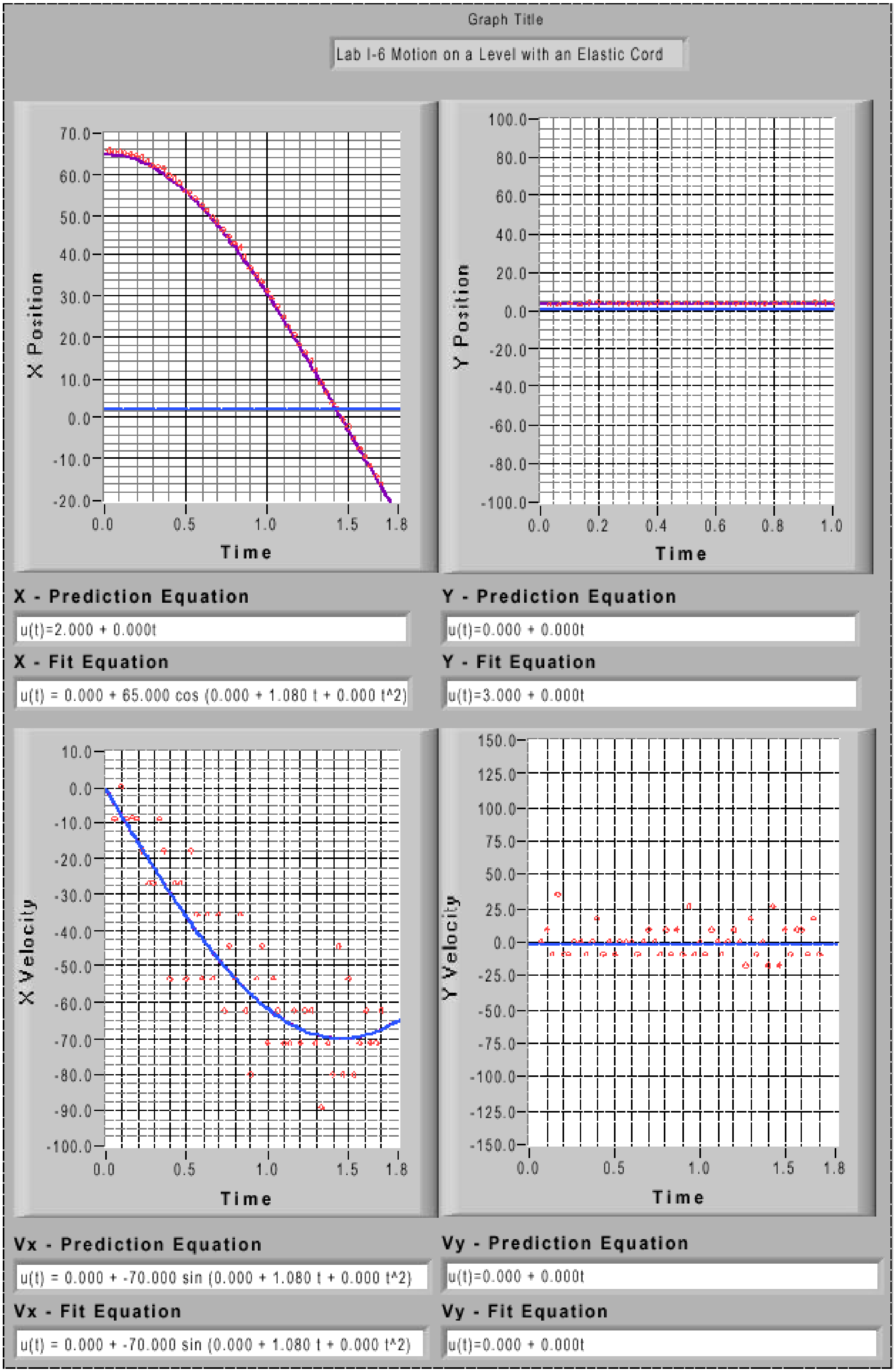
Prediction and Warm up questions:

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, I include the result obtained using Hooke's Law below, for your own interest:

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

Where 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 acc 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

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

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?

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? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

____

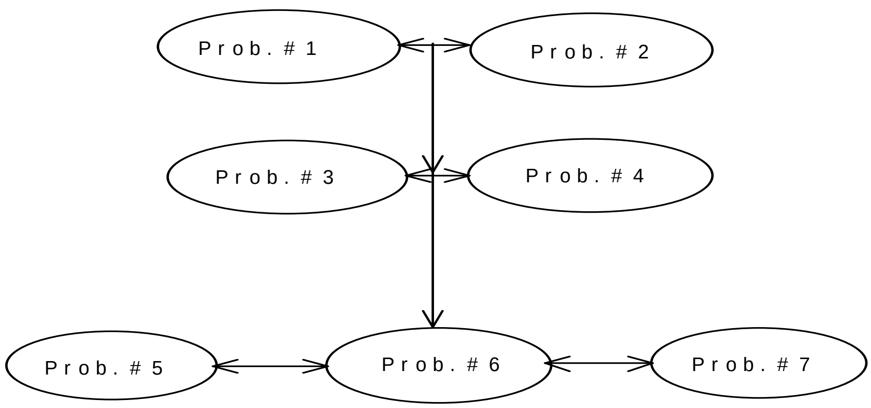
____

____

Laboratory II: Two-Dimensional Motion

This lab is basically a continuation of Lab 1. We want the students 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:

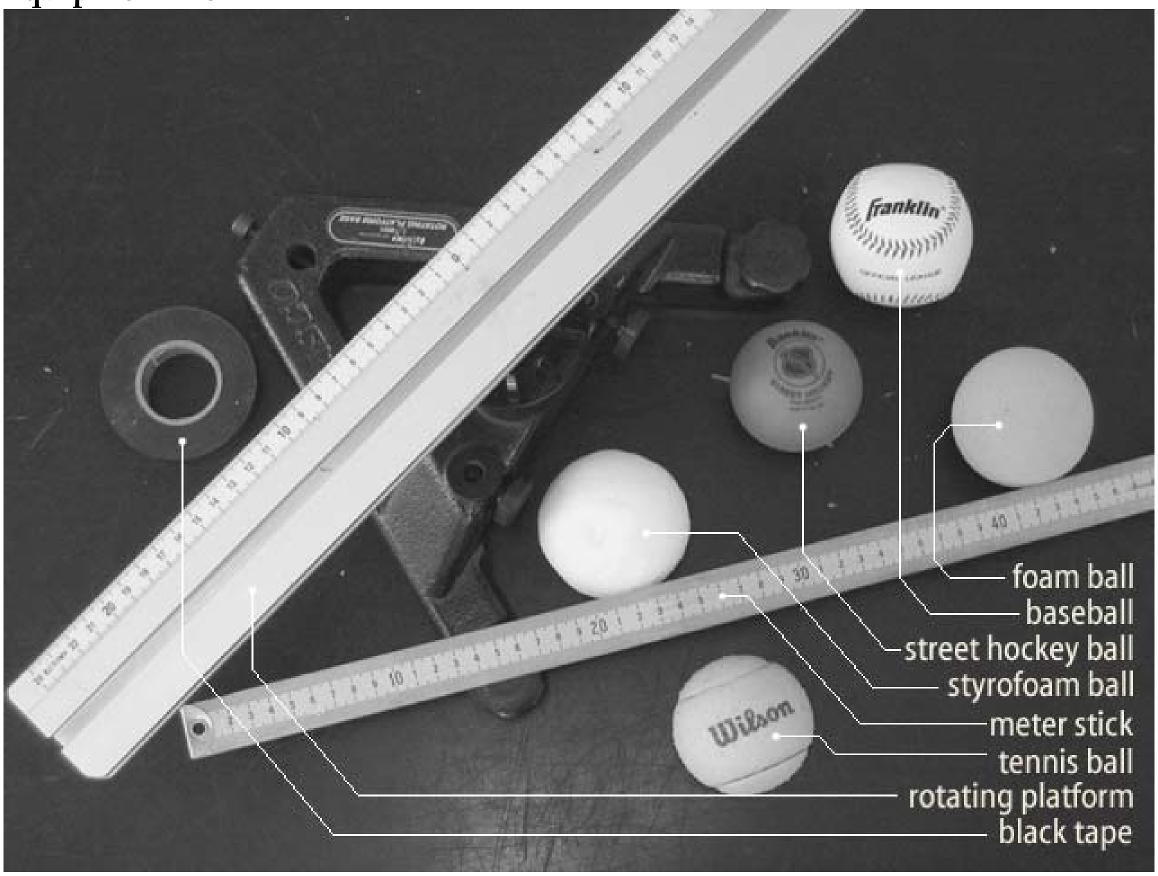
- Determine the motion of an object in free-fall by considering what quantities and initial conditions affect the motion.
- Determine the motion of a projectile from its horizontal and vertical components of motion, and by considering what quantities and initial conditions affect the motion.
- Determine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

- Try analyzing a projectile motion movie so that you can recognize when image splitting occurs due to the camera's interlaced scan. Try out several strategies to deal with this feature of video cameras so that you can recognize when your students are having this difficulty.
- 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.

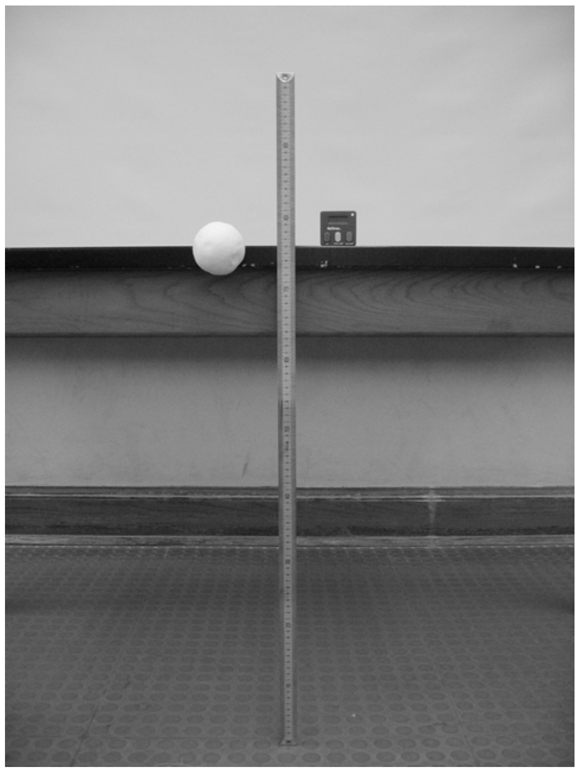
Equipment List:



Problem #1: 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.



Teaching Tips:

1. The answer to this problem is different from in the text; namely, students should observe that heavier objects fall faster. 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.

2. To make this "mass effect" clearer to you, we include the following equations:

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

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

   Where t and s stand for tennis ball and Styrofoam ball, respectively (we use these for an example.) F is the total force on the ball (=ma), W is the weight of the ball (=mg), 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 **can not** and **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.

3. 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?

4. 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.

5. Encourage your students to use significant mass differences. Ask them what a significant difference is.

6. 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:

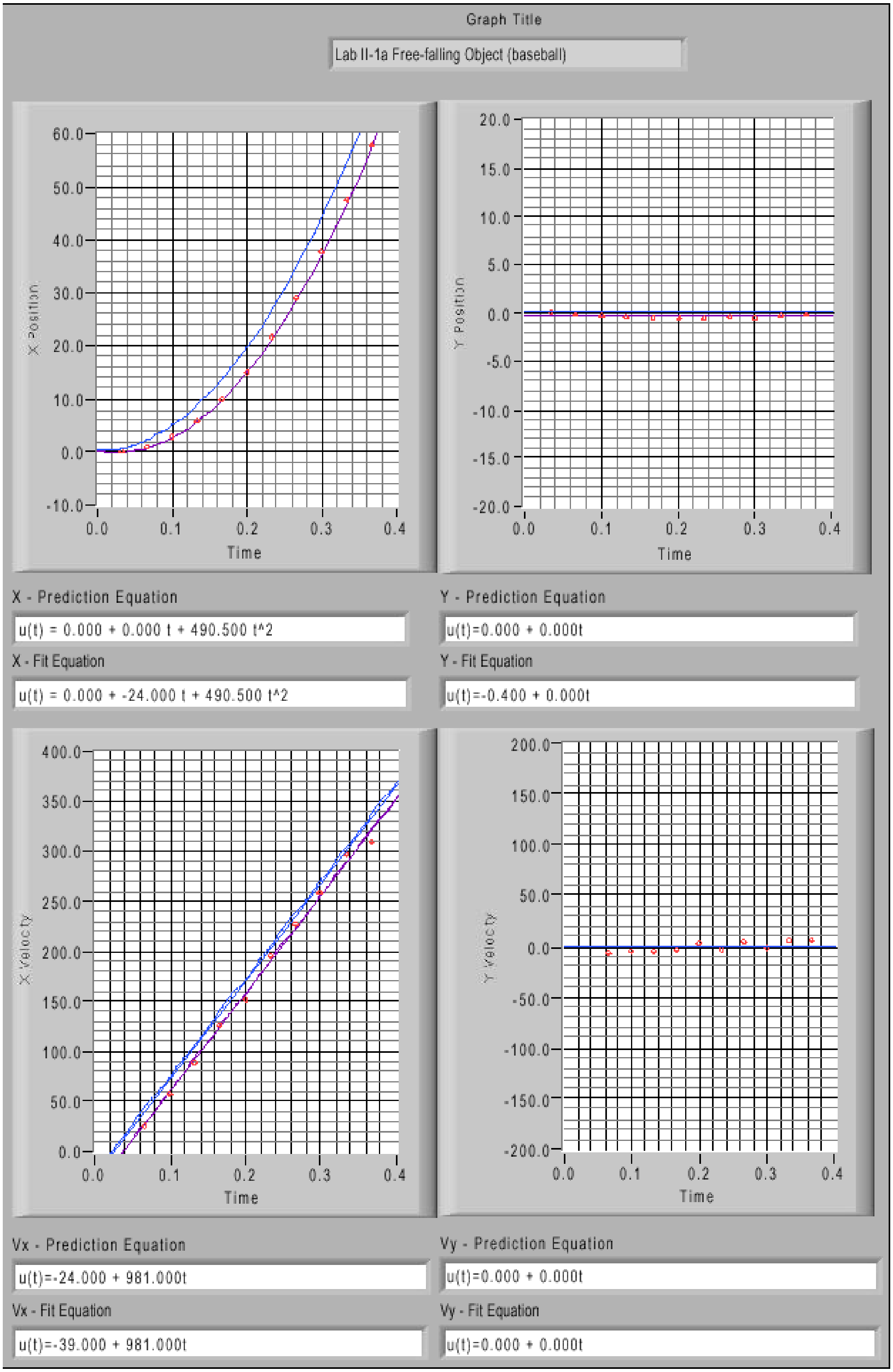
Neglecting air-resistance, all the balls should fall with the same acceleration (g).

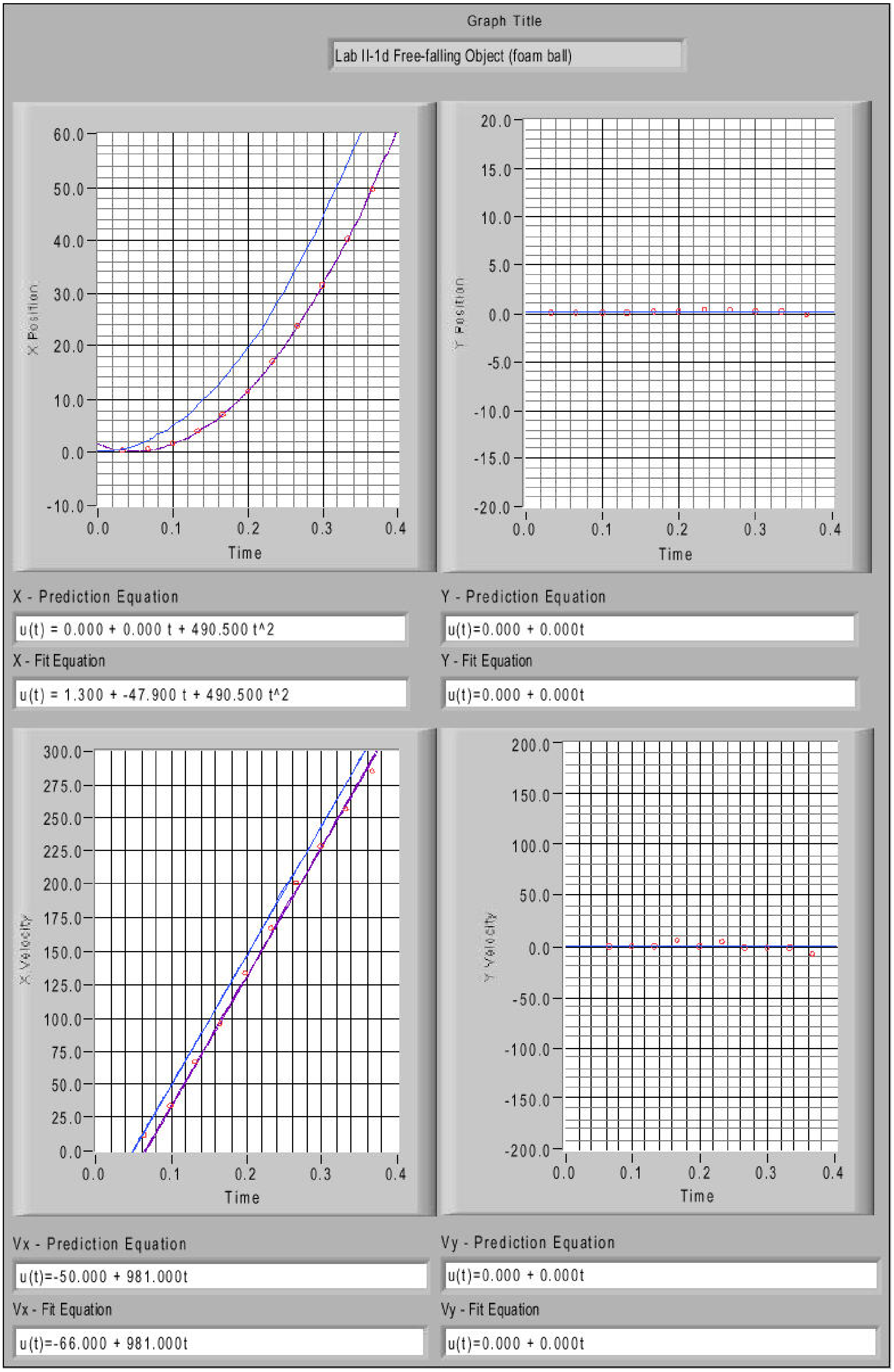
Sample Data:

The printouts for the measurements the baseball and foam ball are included at the end of following sample data.

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 $9.81 m/s^2$.

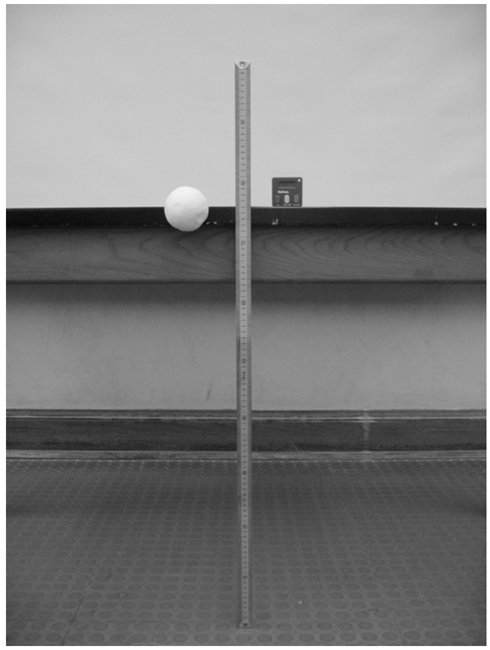

Graph Title
Lab II-1a Free-falling Object (baseball)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 0.000 t + 490.500 t^2
X - Fit Equation
u(t) = 0.000 + -24.000 t + 490.500 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-0.400 + 0.000t
X Velocity
Time
Y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

Problem #2: Initial Conditions

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.



Teaching Tips:

1. 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.
2. This problem is a bit tough to do because it is difficult to get a wide range of initial velocities for the movies.
3. 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.
4. 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:

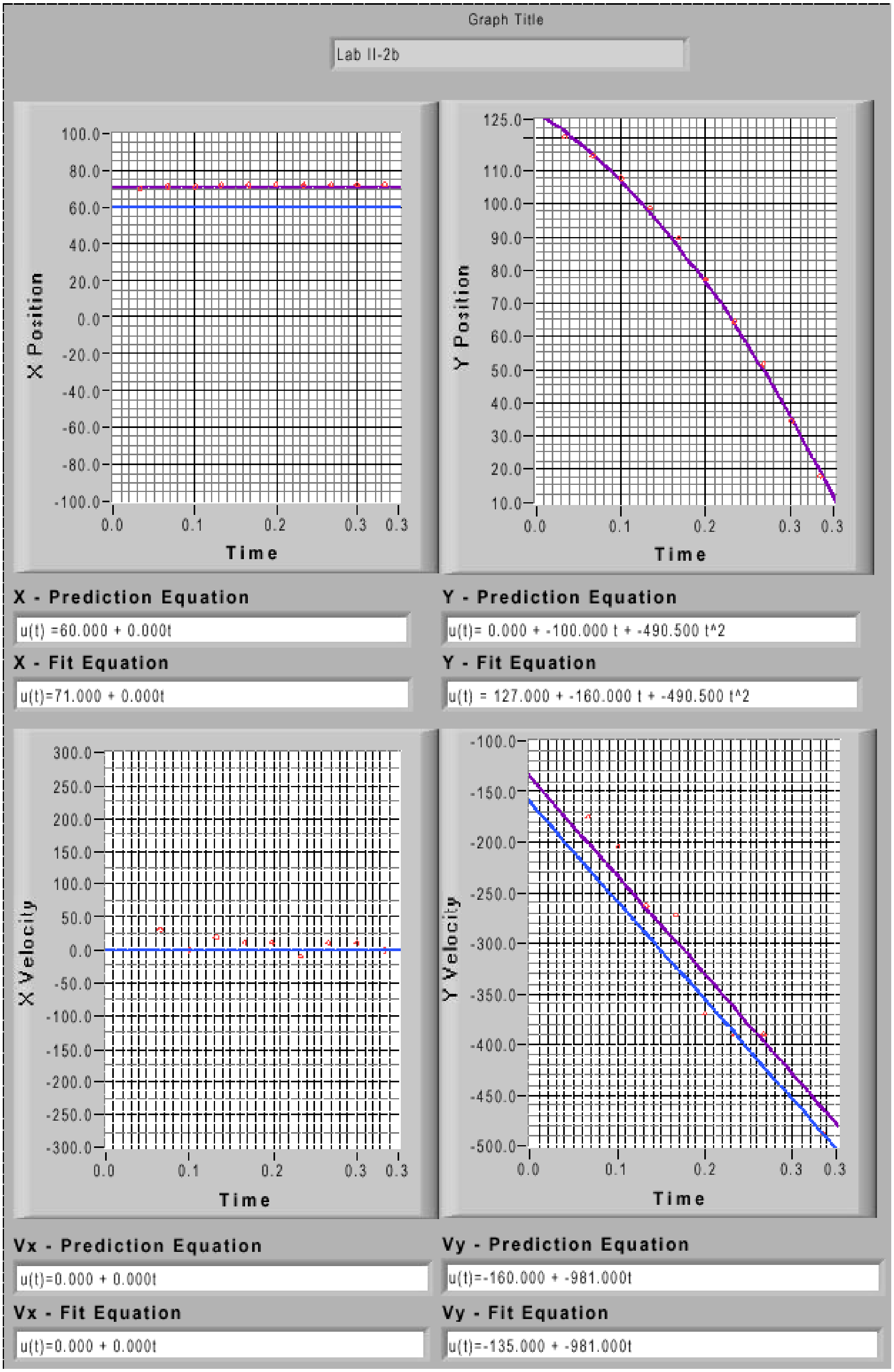
The major alternative conception here is that the ball with the largest initial velocity will have the largest acceleration or that the hand somehow “impresses” acceleration on the ball.

Prediction and Warm up questions:

Acceleration is independent of initial velocity (acceleration = g).

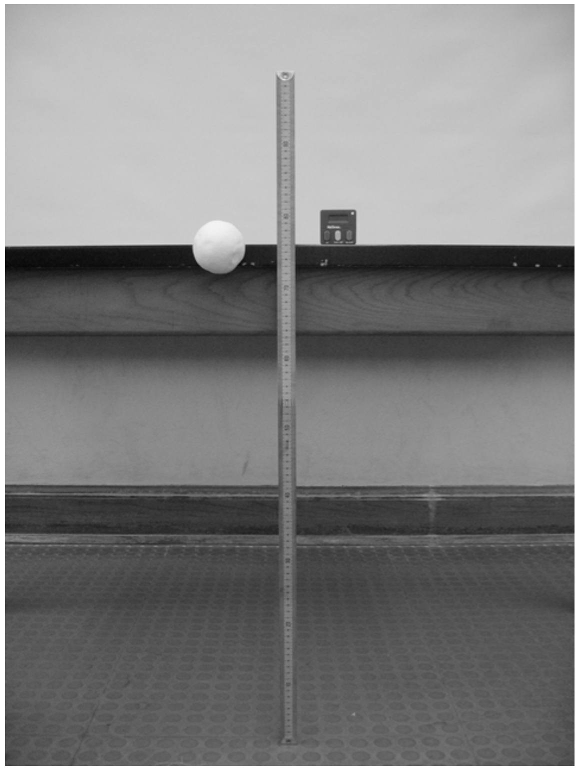
Sample Data:

One printout at an initial velocity is included at the end of following sample data.
Using street hockey ball: mass = 47.49g, diameter = 6.56cm. For three different initial speeds, accelerations are all $9.81 m/s^2$.


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

Problem #3: 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.



Teaching Tips:
1. 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.
2. 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*.
3. 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:

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

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

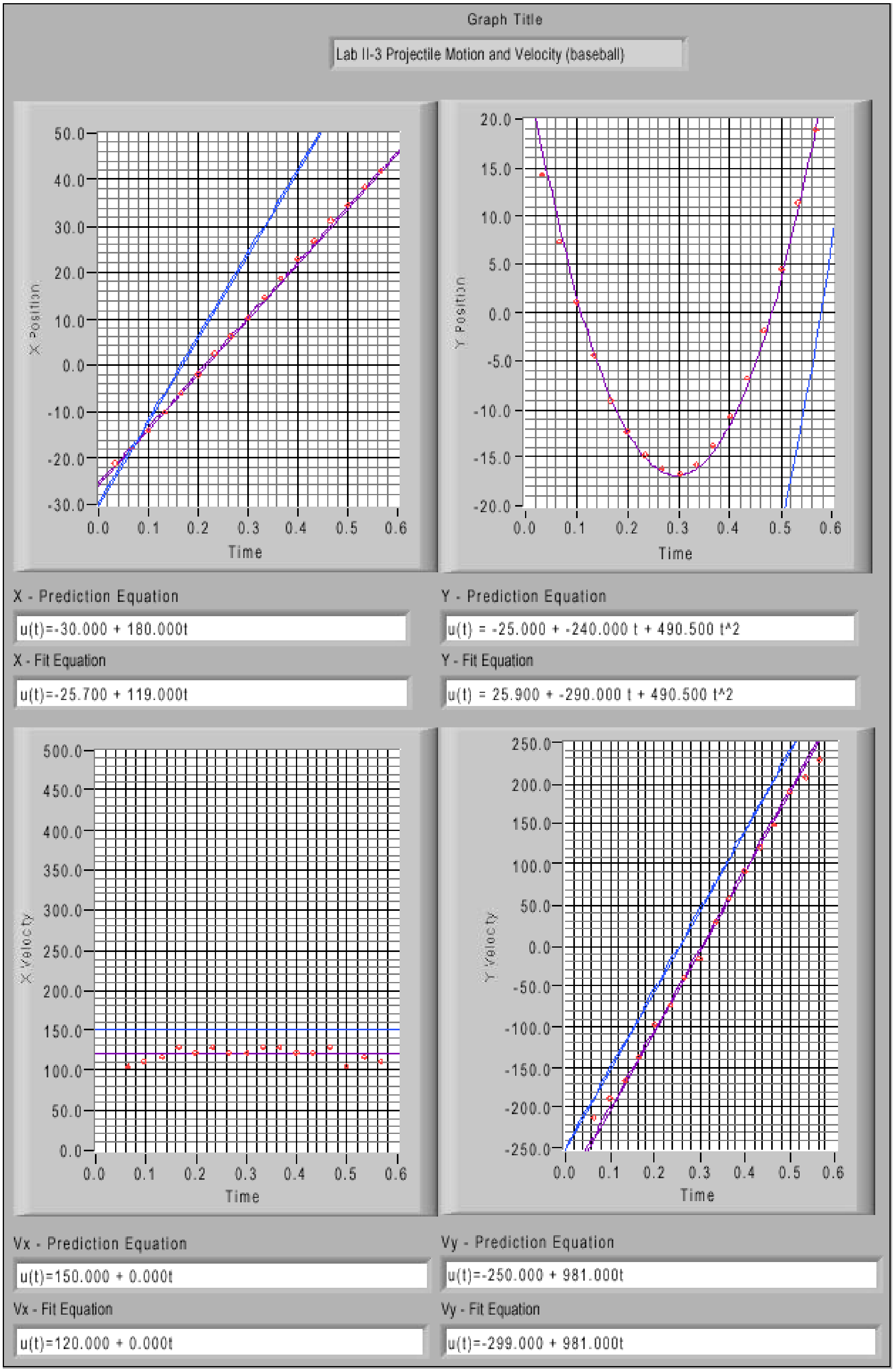
where v_{ix} is the horizontal component of the initial velocity, v_{iy} is the vertical component of the initial velocity, and the initial position of the ball is taken to be the origin of the coordinate system.

Sample Data:

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

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

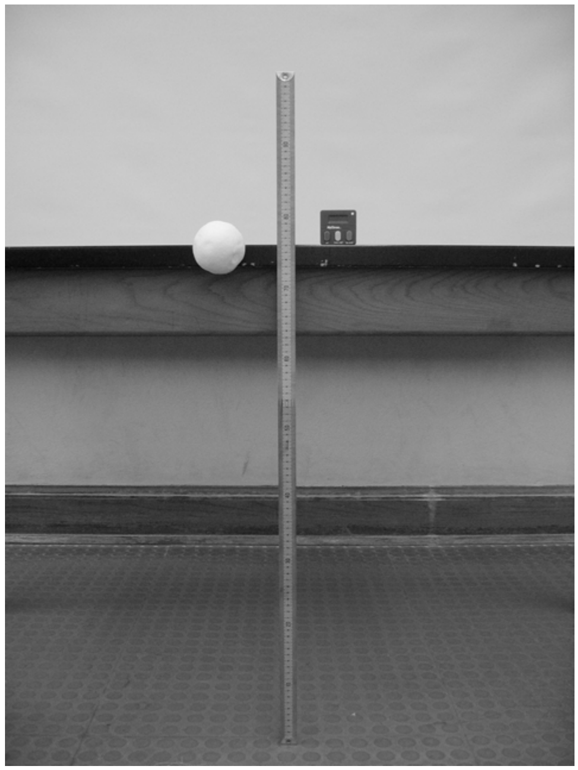
The motion along X (horizontal) axis is a constant velocity motion with velocity 119 cm/s, and the motion along Y (vertical) axis is a constant acceleration motion with acceleration 981 cm/s^2, with the defined positive directions for both axes.


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

Problem #4: 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.



Teaching Tips:

1. *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.

2. 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.

3. 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.

4. 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.

5. 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.

6. 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.
7. 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 Appendix B.

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 them about it at this time.]

Sample Data:

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

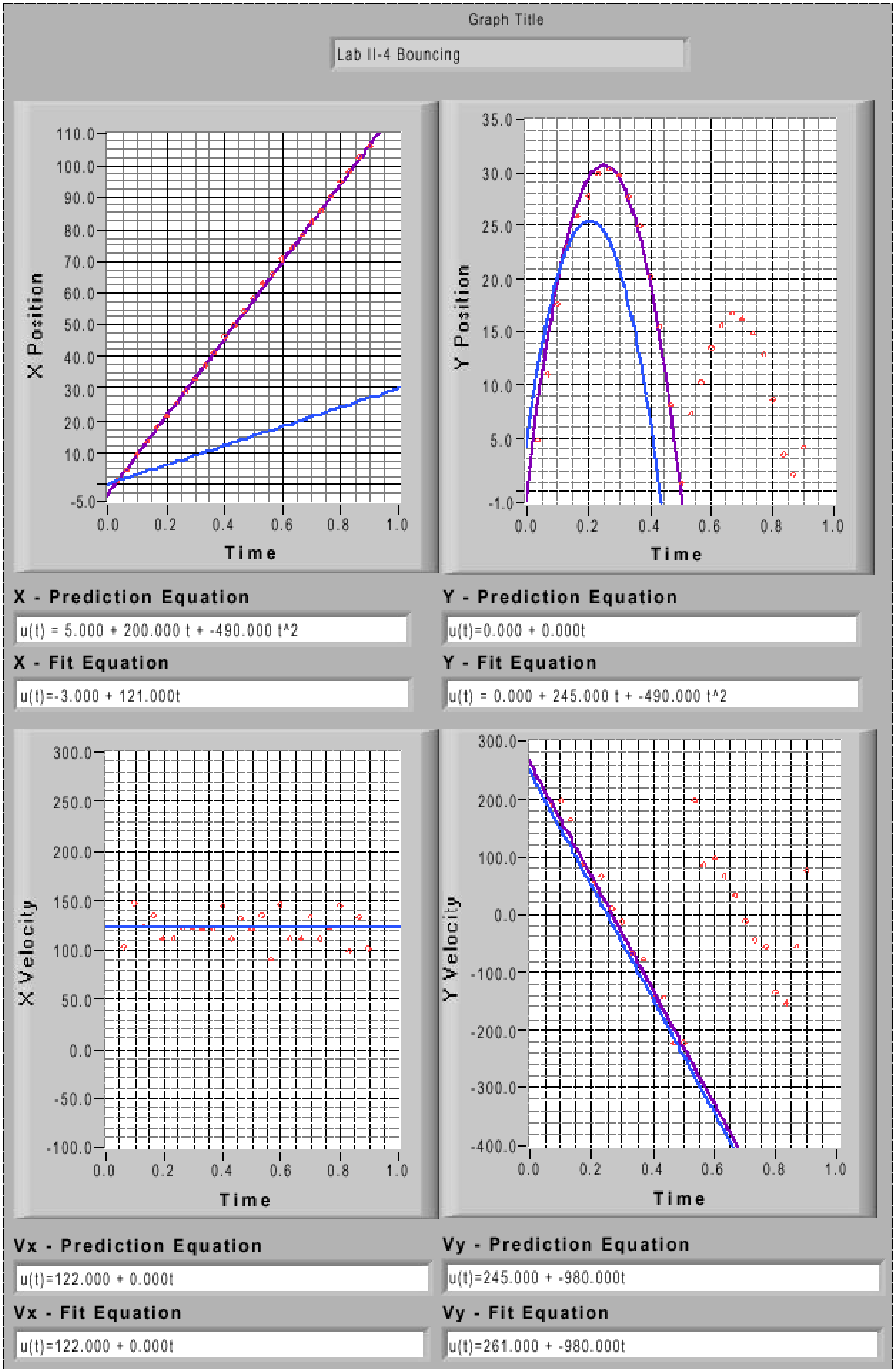
$v_{0x} = v_{1x} = 121$ (cm/s),

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

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

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

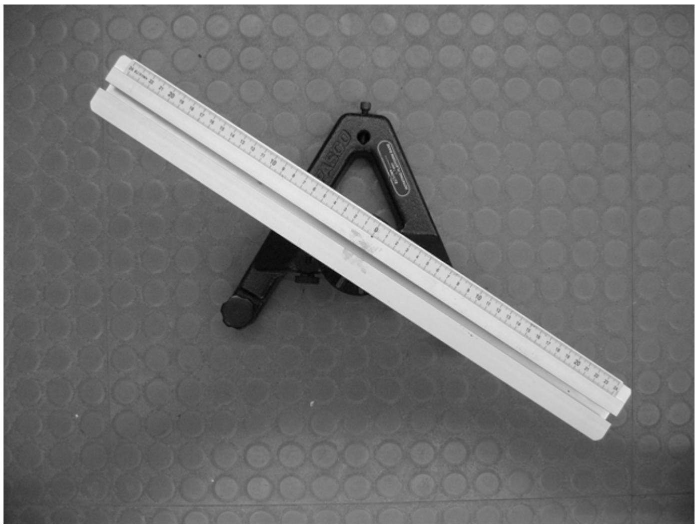
Measured $\frac{x_0}{x_1}$=1.315.


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

Problems #5, #6, and #7: Circular Motion

Purpose:

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



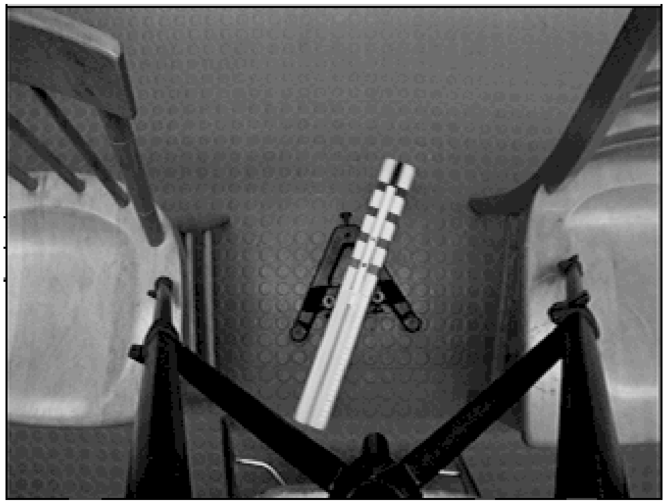
Teaching Tips:

1. 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.

2. 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.

3. For Problem #7, DO NOT LECTURE about gravitational force. The students don't need to understand it to do the problem.

4. To the right 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.



5. 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 #5:

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

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

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

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

Problem #6: The acceleration is directed radially towards the center of the circular orbit.

Problem #7: $a = \dfrac{4\pi^2 r}{T^2}$, (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.

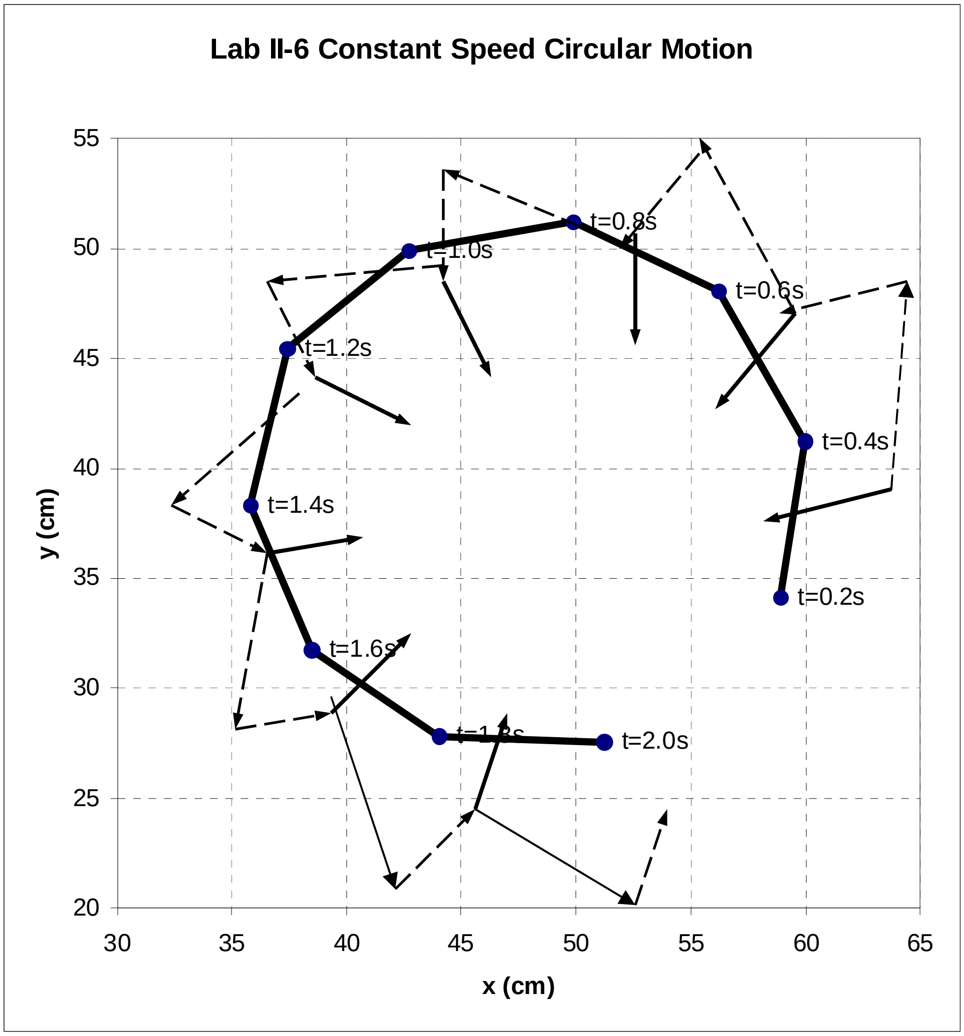
Problem #5
Measured angular speed: 2.93 (rad/s),
Measured radius of rotation: 12.2 (cm),
Acceleration : $a = 104.6$ (cm/s²)

Problem #6
The data are based on the exported data from VideoTOOL.

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

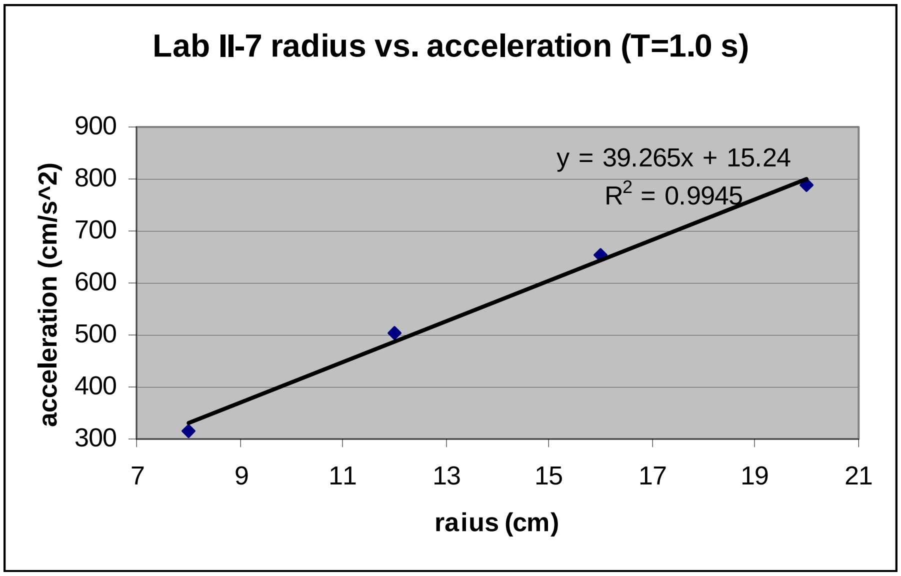
The direction of acceleration for each data point is shown in the following chart. All acceleration vectors point to the center.



Problem #7

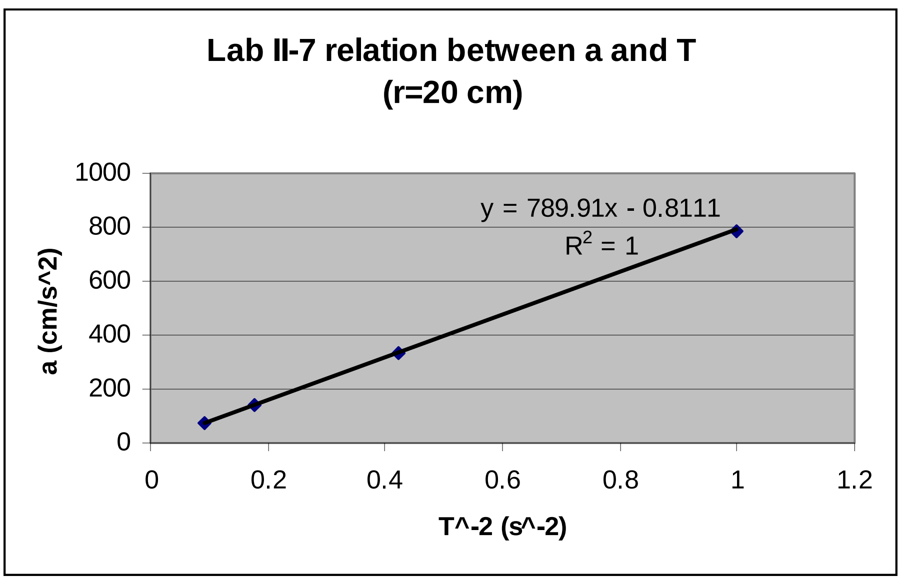
1) T=1.0(s)

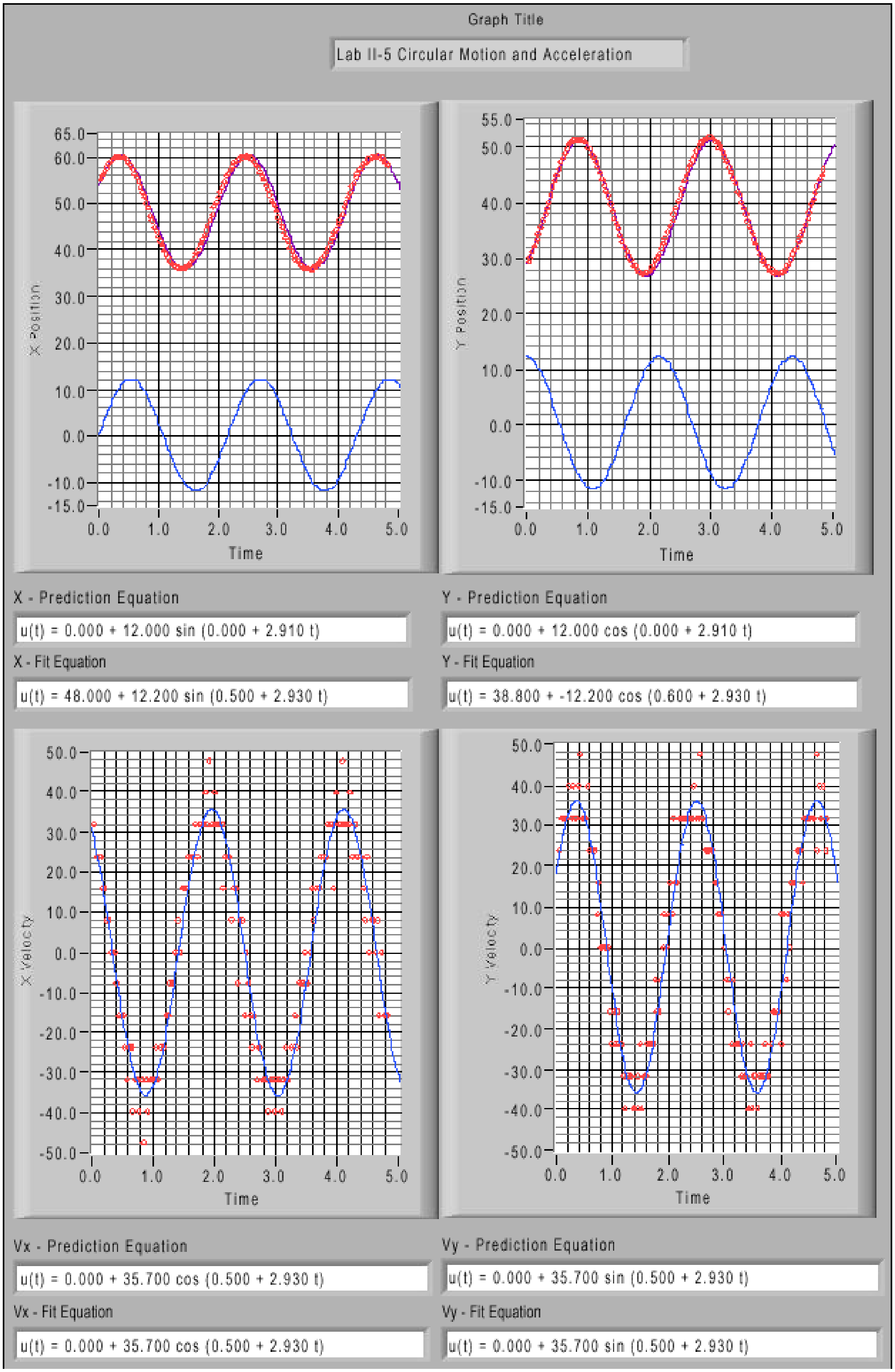
r (cm)	8	12	16	20
a (cm/s^2)	315.5	502.4	653.1	788.8

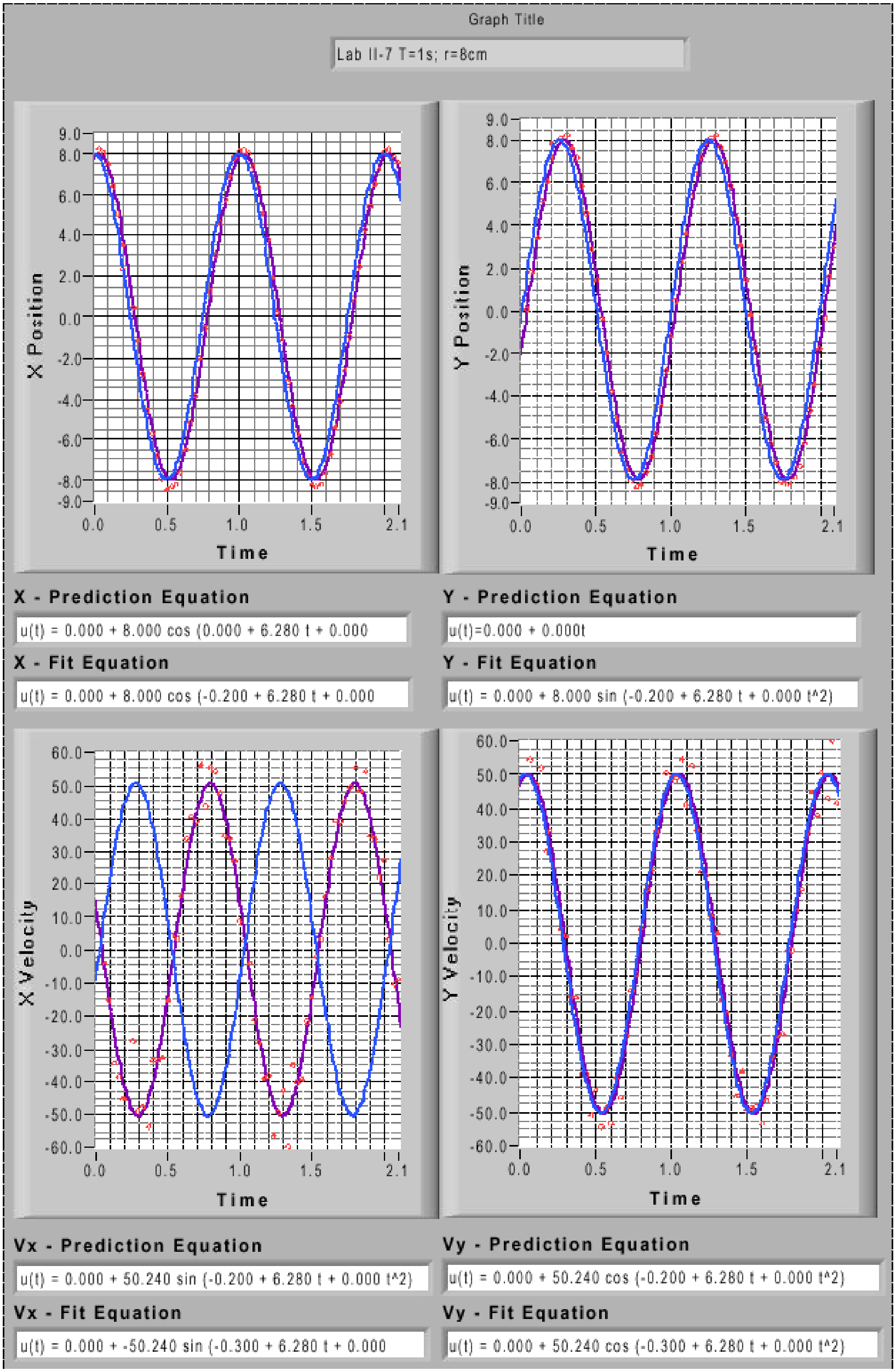


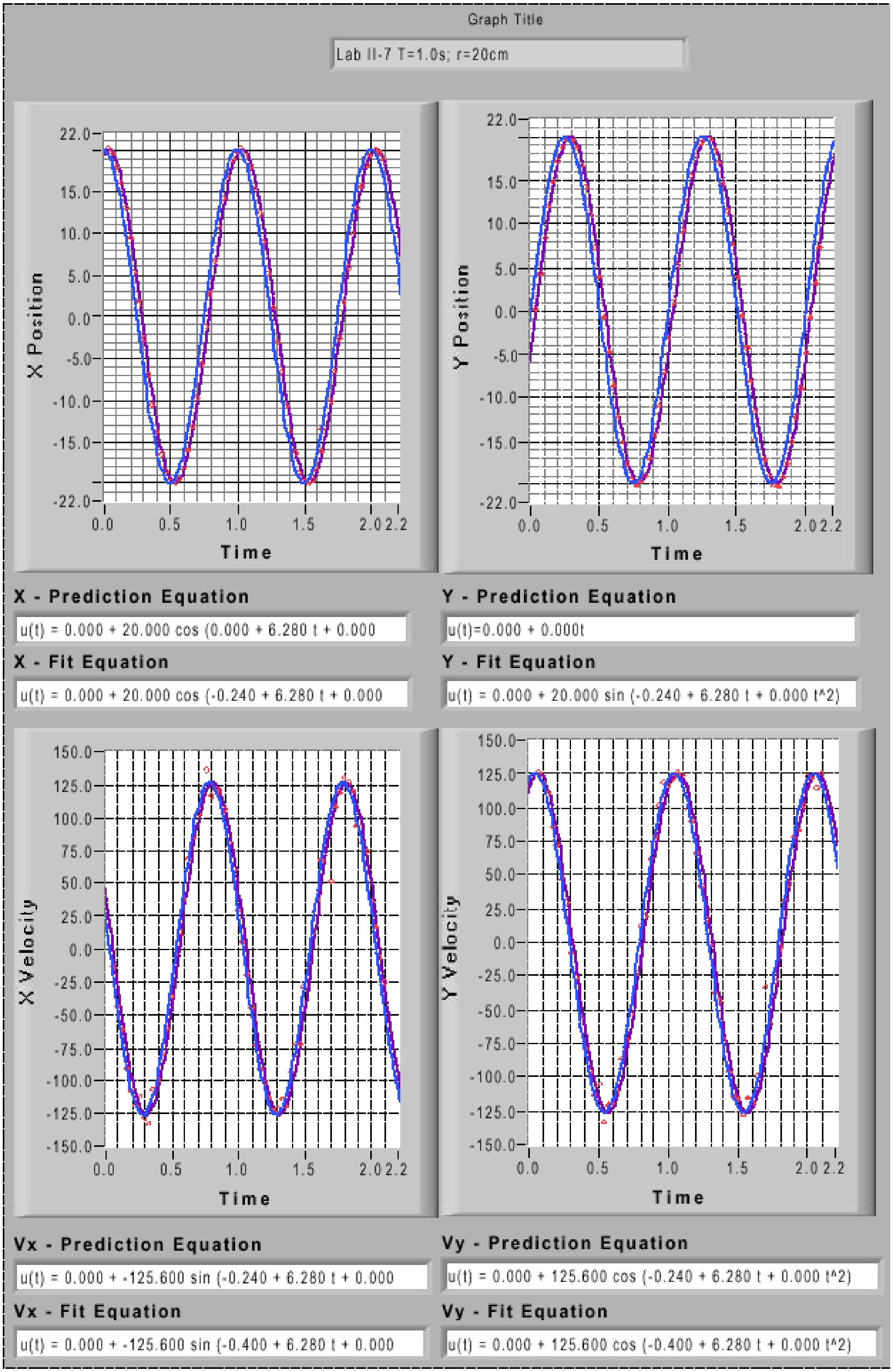
2) r =20(cm)

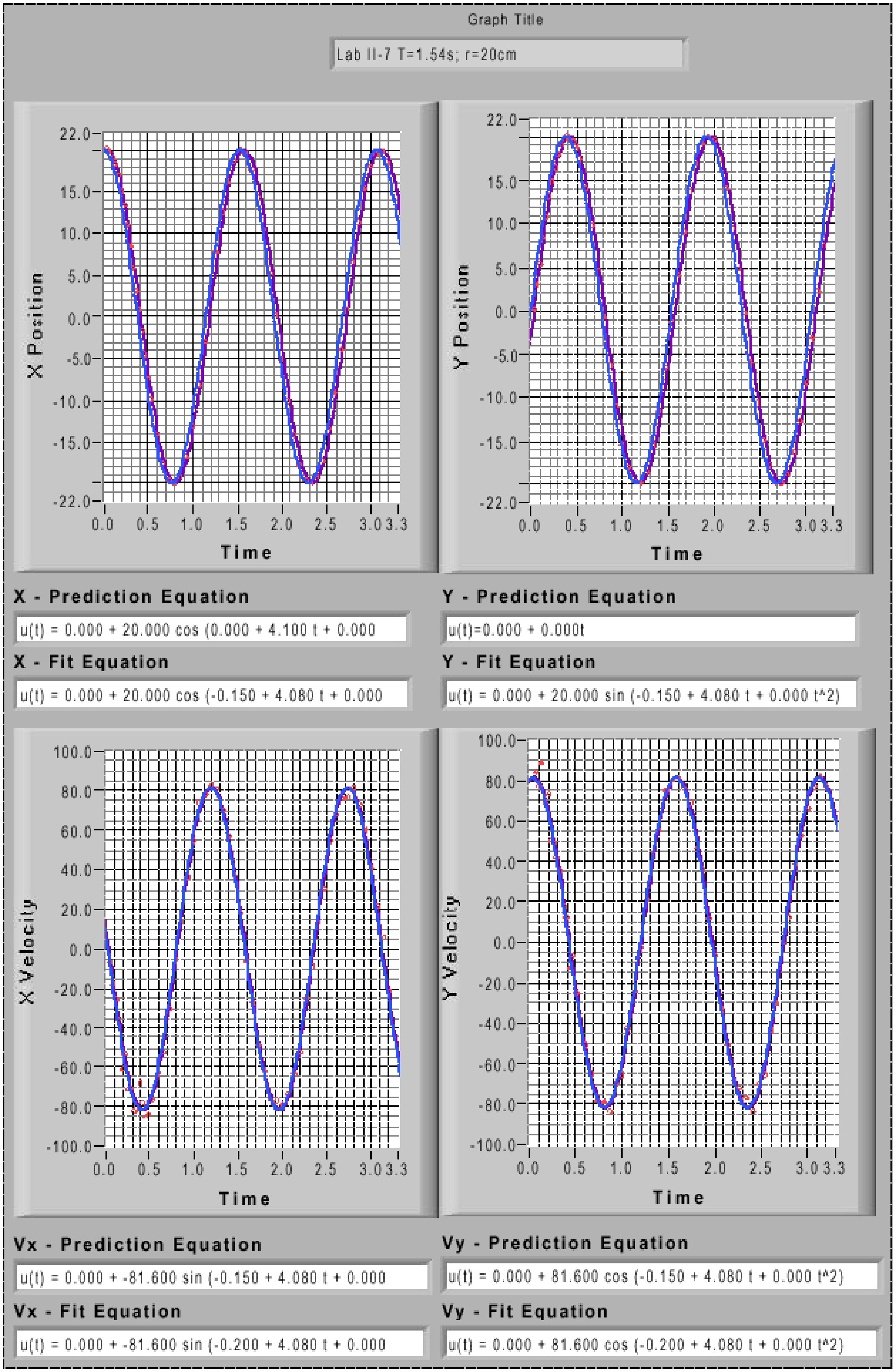
T (s)	1	1.54	2.37	3.3
T^{-2} (s^{-2})	1	0.422	0.178	0.092
a (cm/s^2)	788.8	332.9	140.5	70.7




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
9.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-9.0
0.0
0.5
1.0
1.5
2.1
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
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
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
Y Position
Time
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
Y Velocity
Time
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 2

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

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?

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? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

____

____

____

Laboratory III: Forces

General Teaching Tips

1. 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.

2. 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.

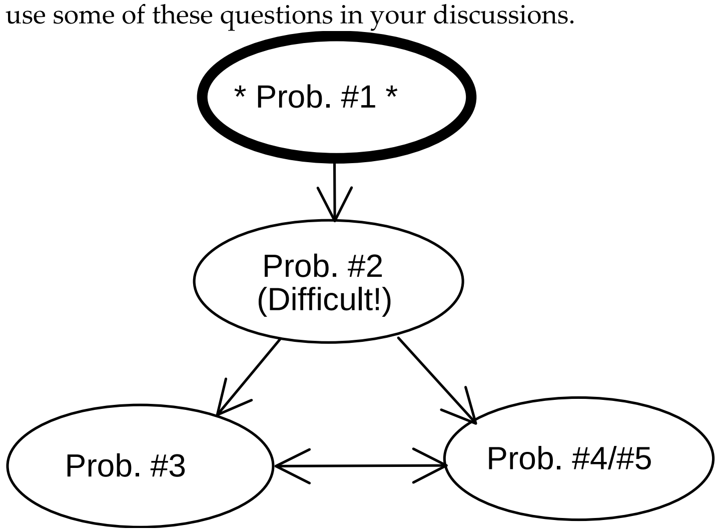
3. Problems #4 and #5 are similar. You might consider dividing the class in half and letting each half do one problem. The halves can then combine into two large groups, compare their data, and each large group can do a 5-minute presentation.

4. 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.

5. 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.

6. 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.

7. 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 discussions.



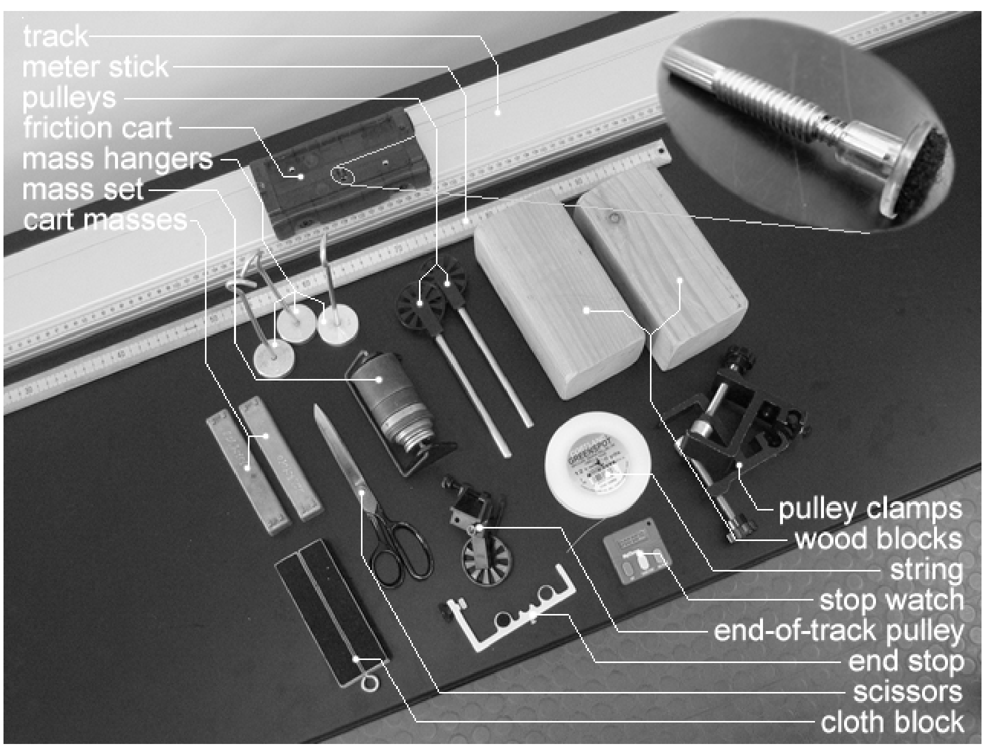
By the end of this lab students should be able to:

- 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.

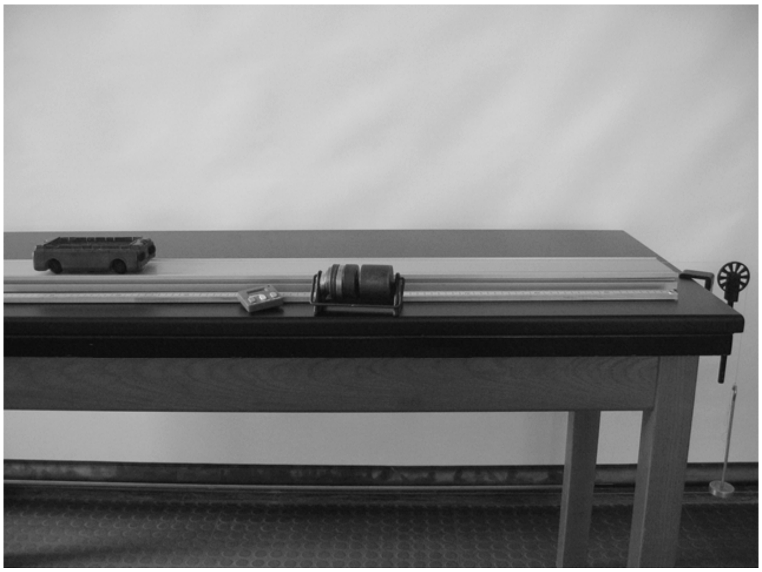
Equipment List:



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.



Teaching Tips:

1. 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.

2. It is amazing how quickly students forget kinematics. This problem will reinforce the idea that physics builds upon itself.

3. 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.

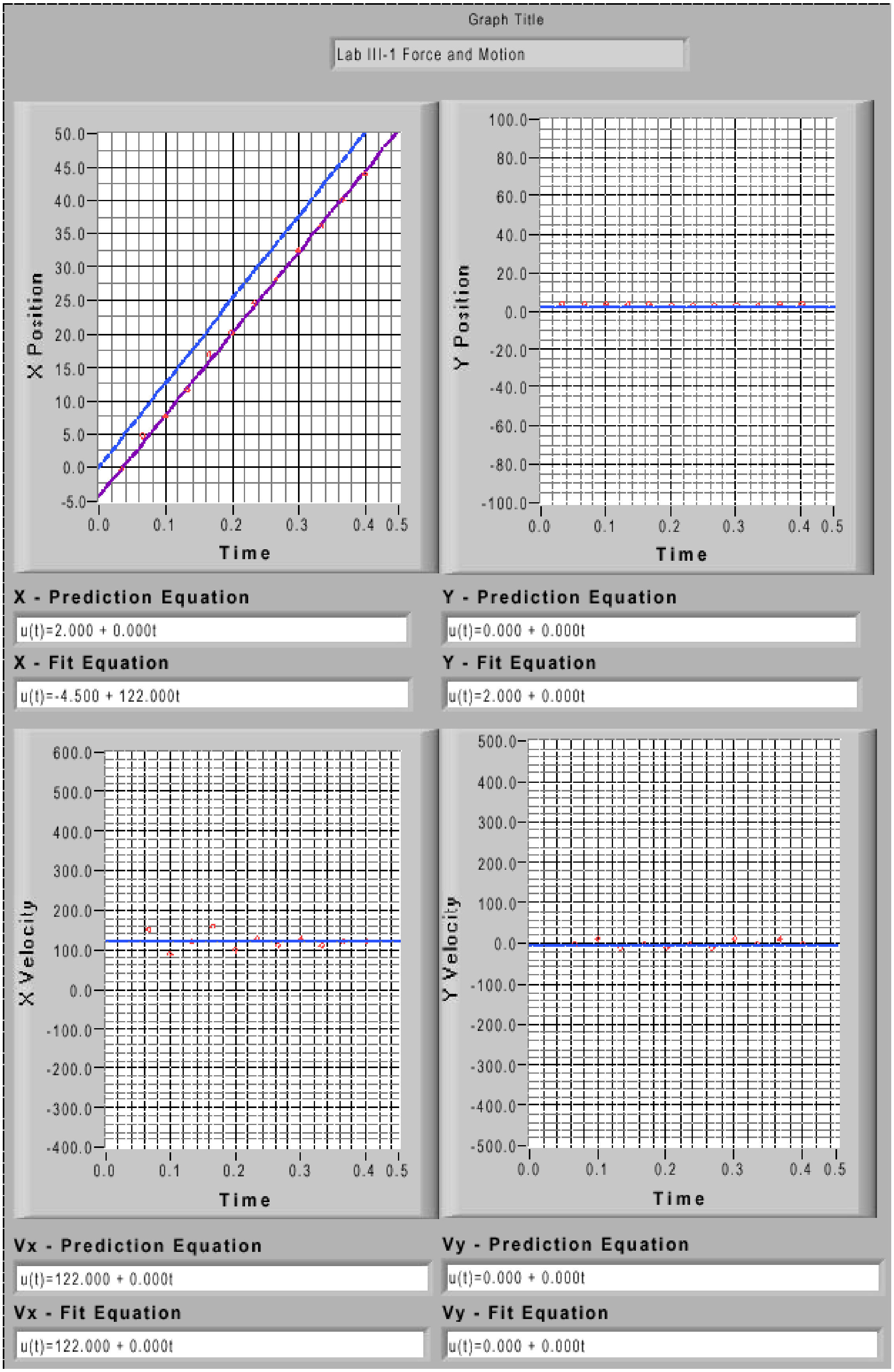
Prediction and Warm up questions:

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

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:

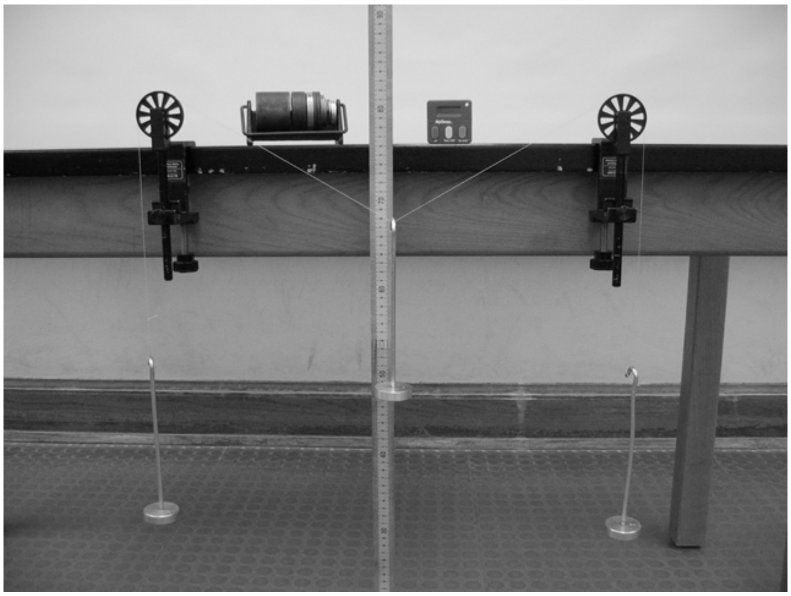
$m = 50.29$ (g), $M = 251.65$ (g), $h = 50$ (cm),
Predicted final velocity of the cart: $v = 1.28$ (m/s),
Measured final velocity of the cart: $v = 1.22$ (m/s).


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

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.



Teaching Tips:

1. 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 soluble.

2. 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.

3. 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.

4. 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.

5. 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.

6. 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.

7. For the sake of the analysis, assume no error on the masses. They can check this assumption with a balance.

8. Encourage the students to explore both mass ranges 0<M<m and M>m.

9. 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_A = 119.12g; m_C = 119.21g
Distance between two pulleys: L = 40.0cm

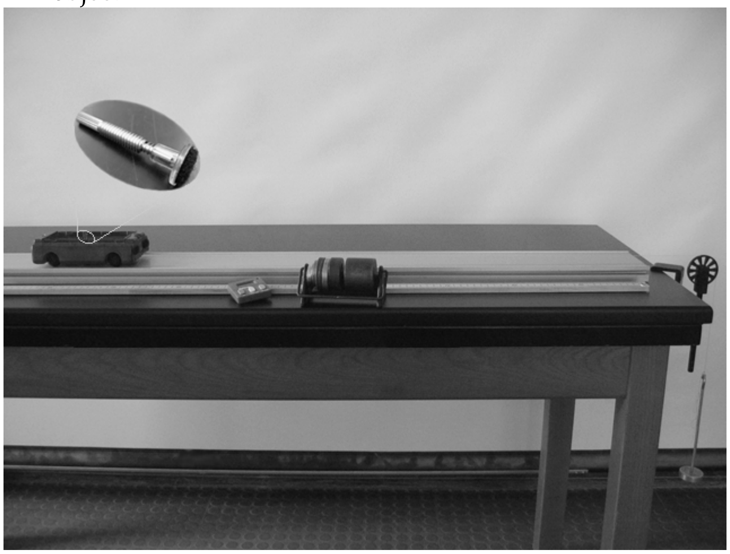
Mass of the suspended object M (g)	Predicted vertical displacement h (cm)	Measured vertical displacement h (cm)
49.48	4.2	4.2
68.85	6.0	6.0
77.92	6.9	6.9

In the calculation of the predicted vertical displacement the average value of m_A and m_C was used for m.

Problems #3: Frictional Force

Purpose:

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



TEACHING TIPS:

This lab addresses the question "Is the frictional force on an object larger when the object speeds up than when it coasts?" Be prepared to lead this discussion.

1. 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:

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

$$f_2 = Ma_2,$$

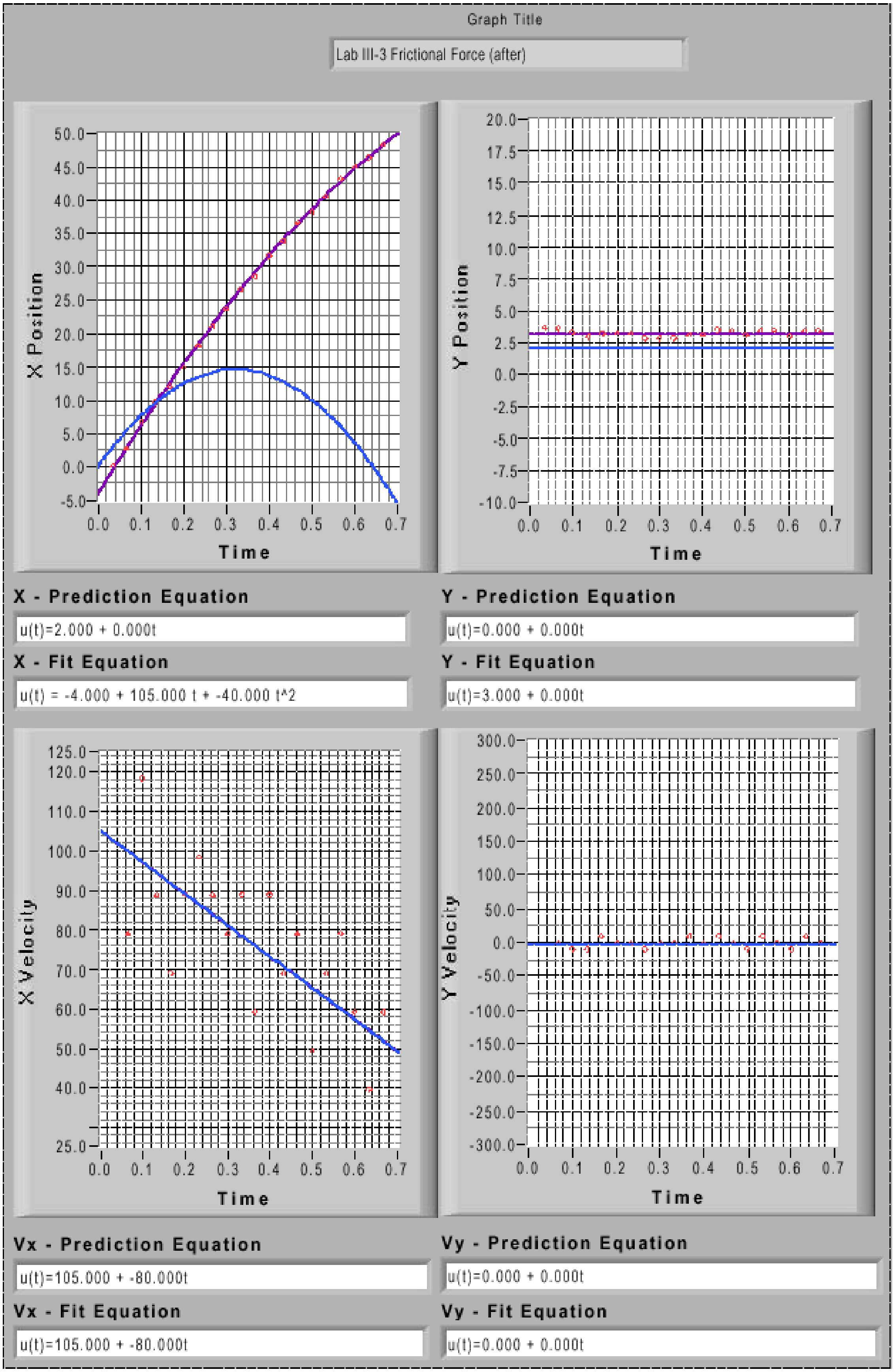
where m is the mass of object A; M is the mass of the cart; f_1 and f_2 are the frictional forces on the cart before and after object A hits the ground, respectively; and a_1 and a_2 are the accelerations of the cart before and after object A hits the ground.

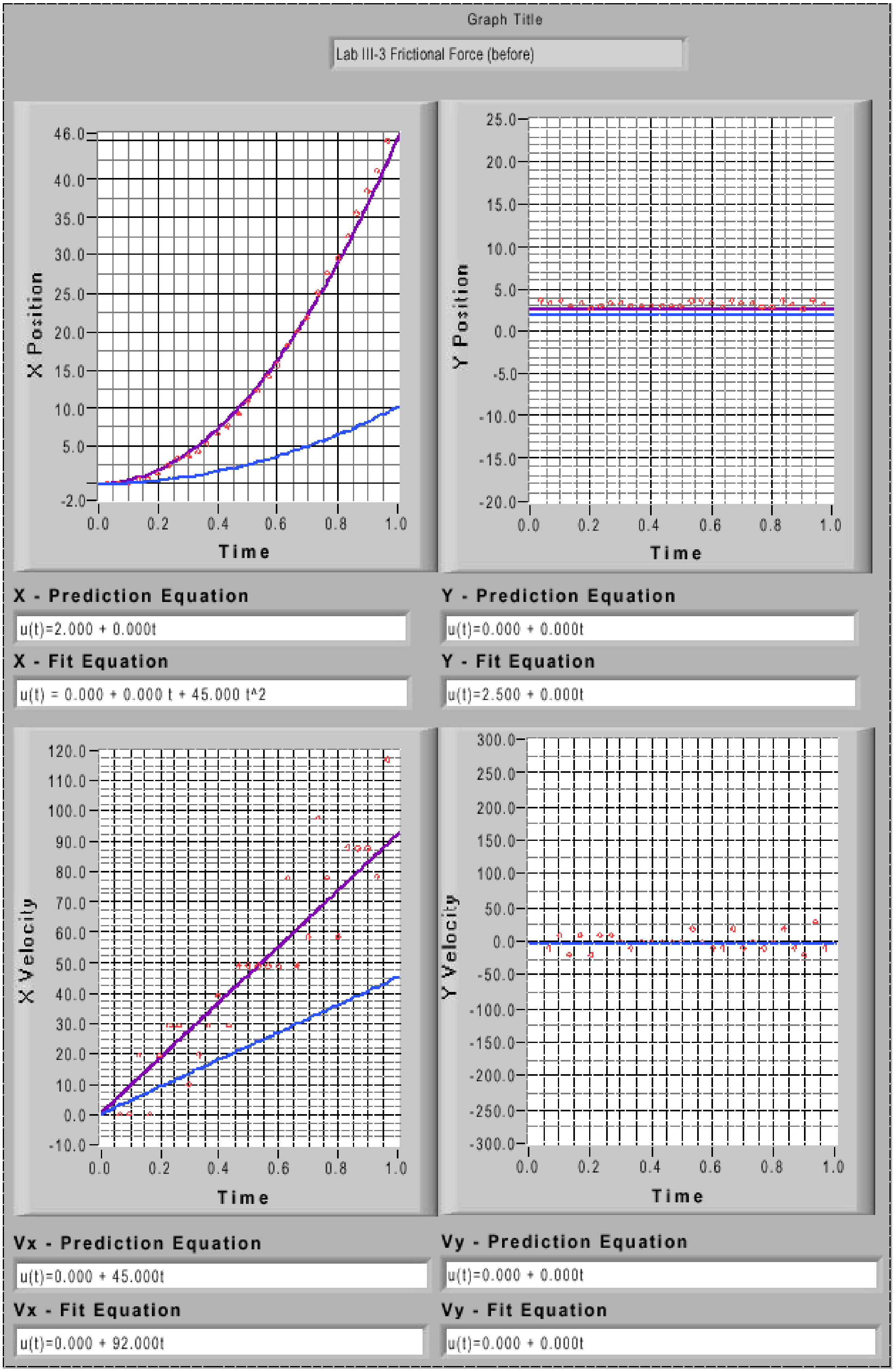
Sample Data:

$m = 50.3$ (g), $M = 259.7$ (g),

Measured acceleration before object A hits ground: $a_1 = 90$ (cm/s^2), & after: $a_2 = 80$ (cm/s^2), Calculated frictional force before object hits ground: $f_1 = 0.214$ (N), & after: $f_2 = 0.208$ (N).

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

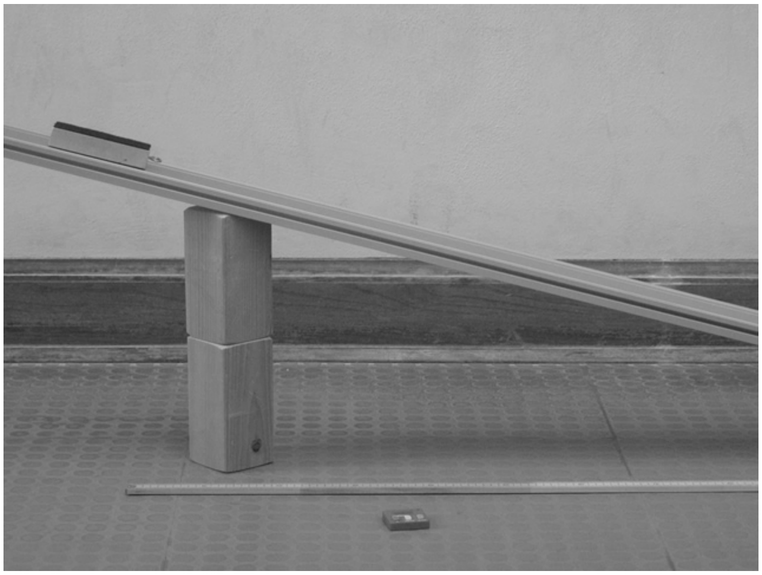

Graph Title
Lab III-3 Frictional Force (after)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=2.000 + 0.000t
X - Fit Equation
u(t) = -4.000 + 105.000 t + -40.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction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

Problems #4 and #5:
Normal Force and the Kinetic Frictional Force (Parts I and II)

Purpose:

- To show that 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).



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.

1. Be sure the block doesn't slide along the yellow ruler tape.
2. 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:

$N = mg\cos\theta$,

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

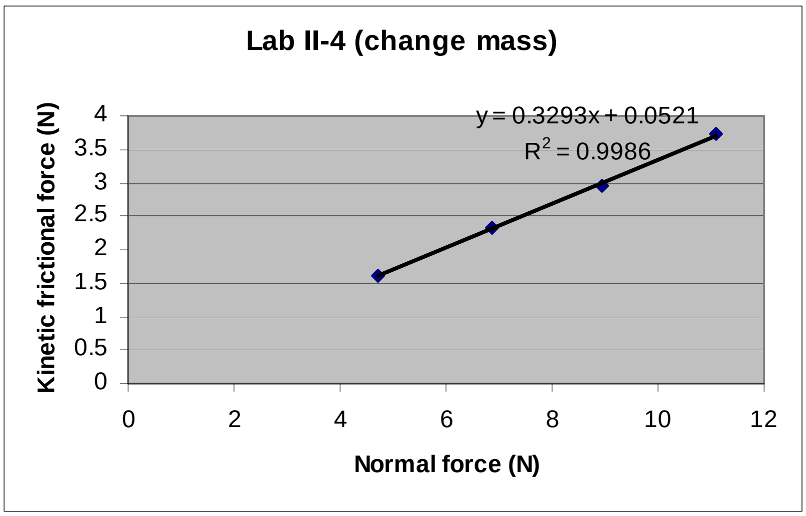
where θ is the angle of incline of the track to the horizontal, m is the mass of the wooden block and a is the acceleration of the wooden block moving down along the inclined track.

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

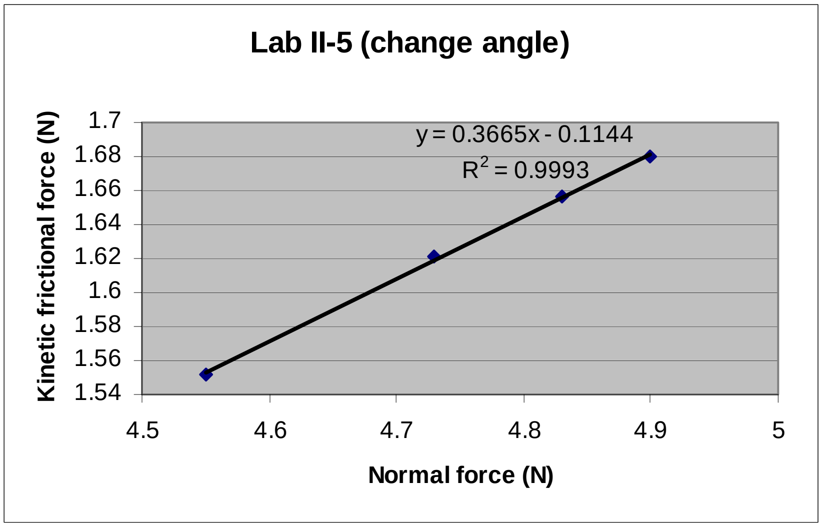


$$\mu_k = 0.3293 .$$

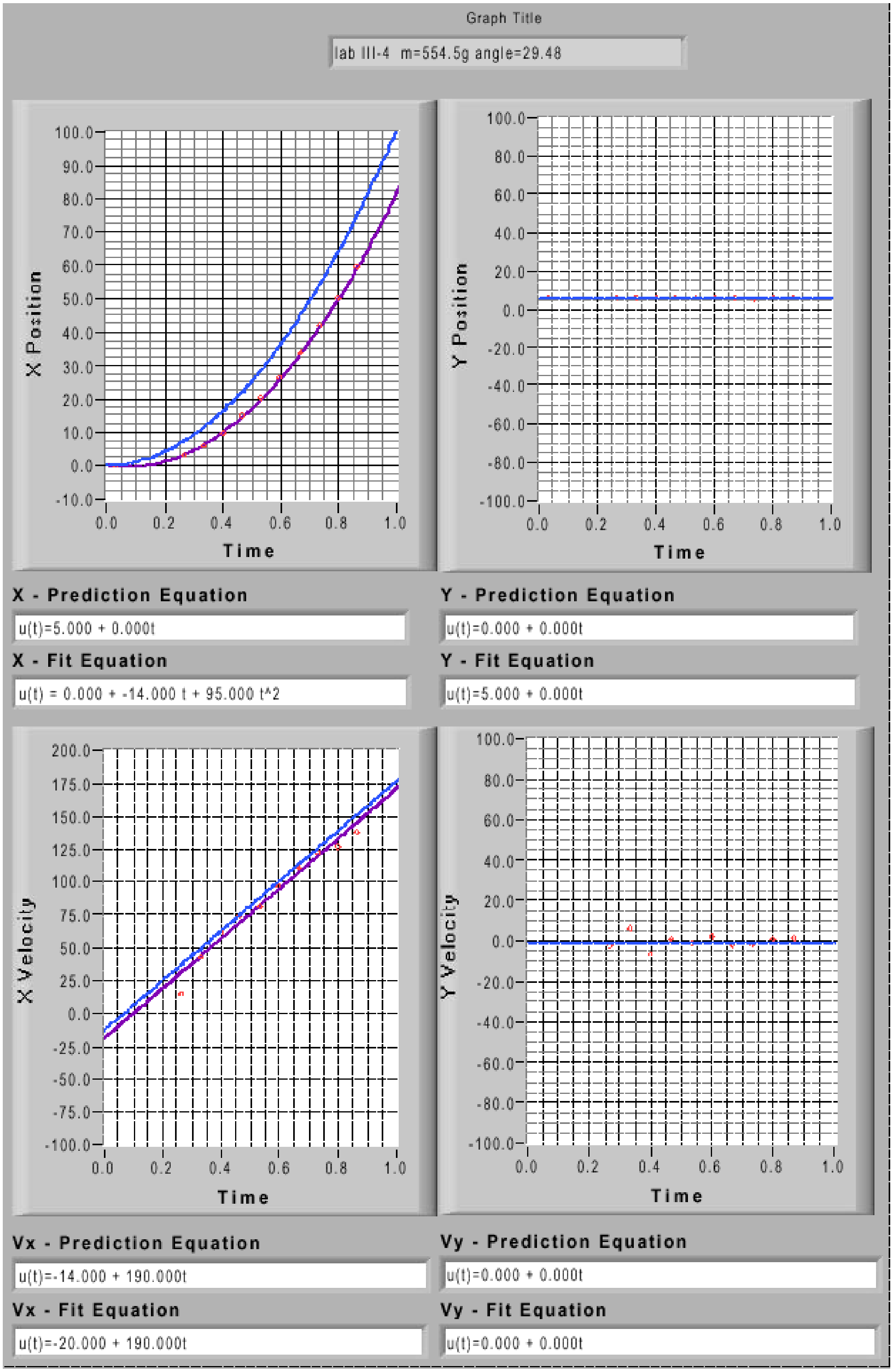
Problem #5:

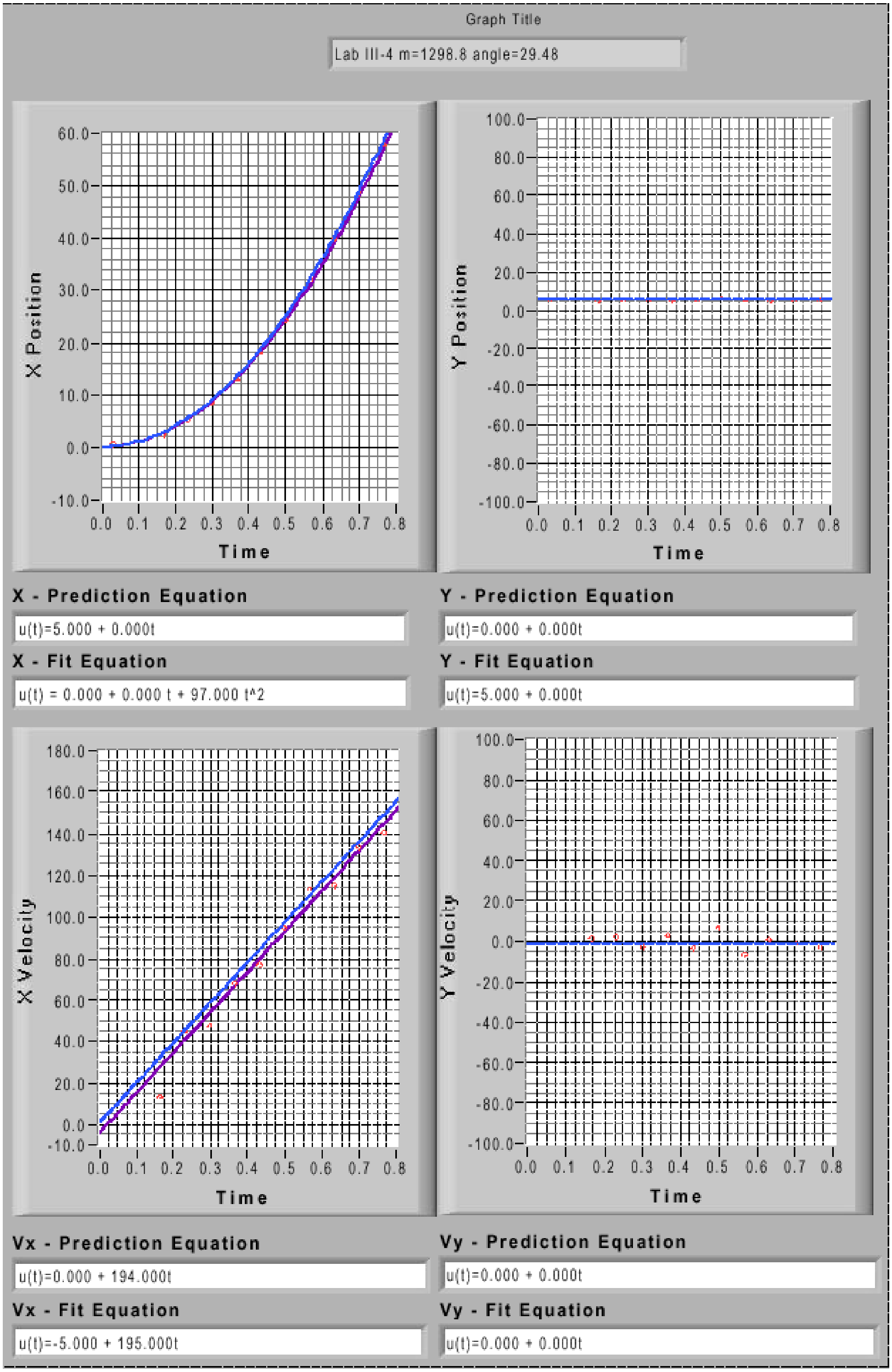
Mass of the wooden block: $m = 554.5$ (g),

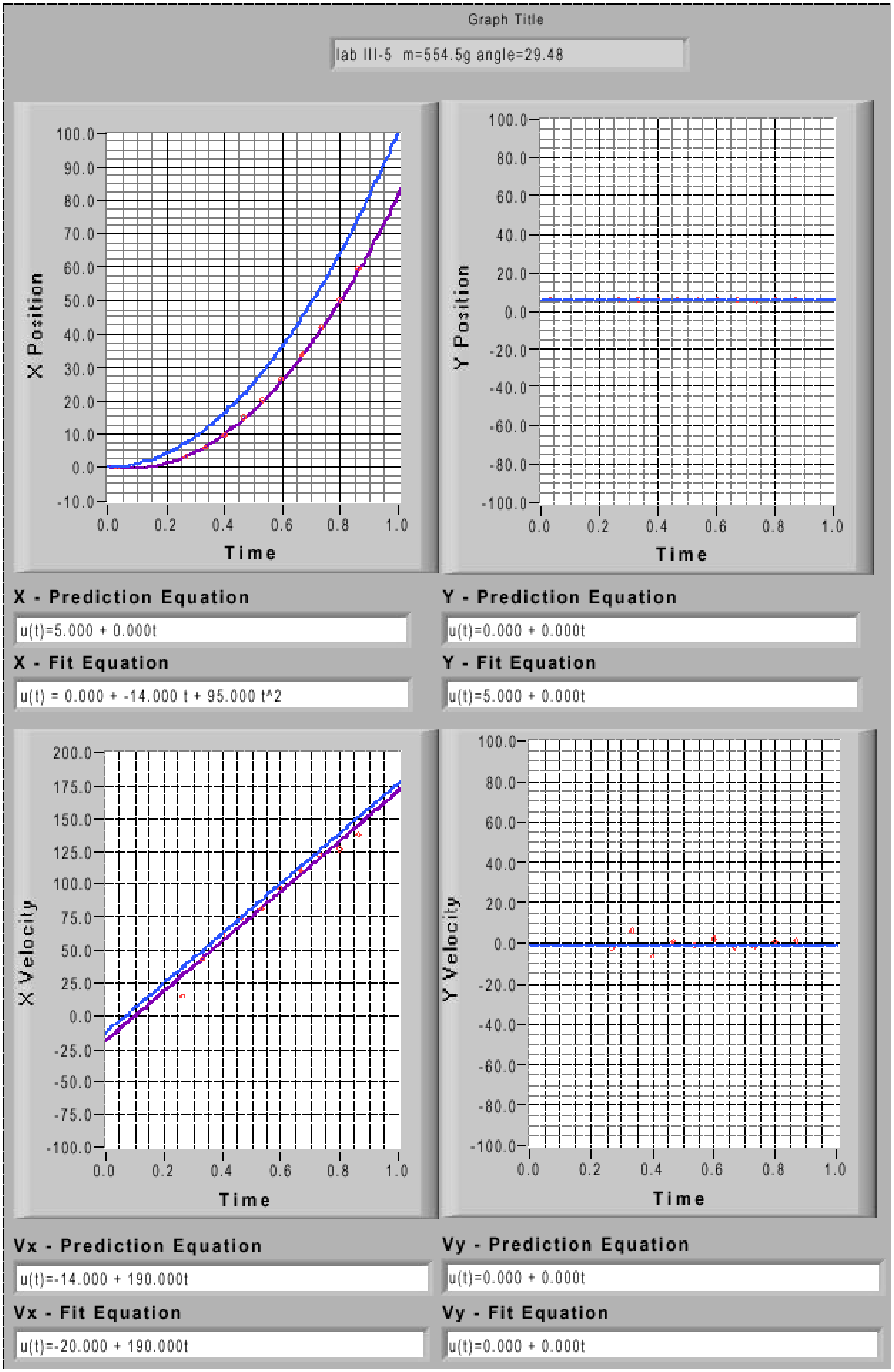
θ (^{0})	25.55	27.21	29.48	33.22
a (cm/s^2)	119.6	149.6	190	257
Normal force N (N)	4.90	4.83	4.73	4.55
Frictional force. f_k (N)	1.680	1.656	1.621	1.552

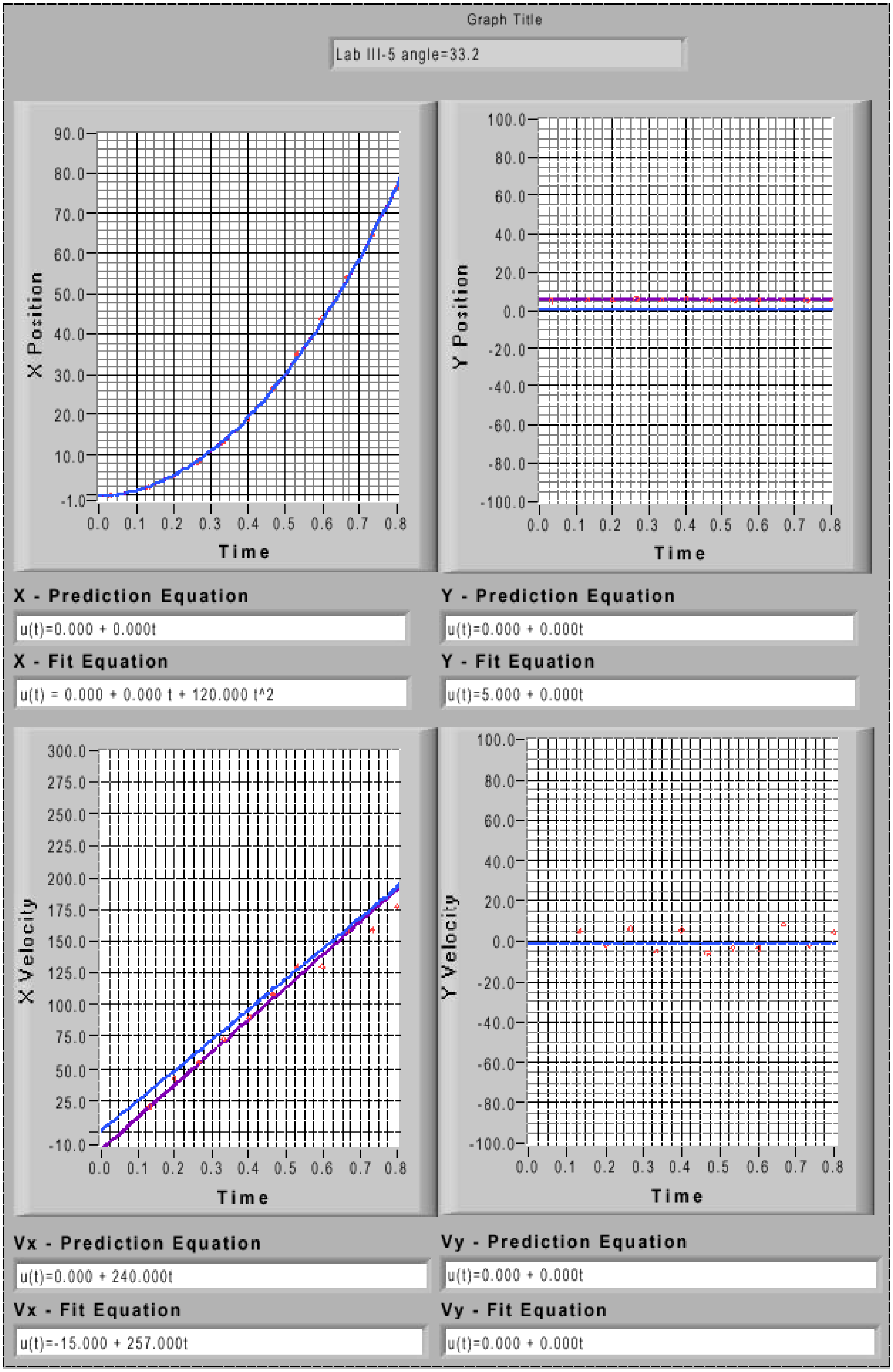

Lab II-5 (change angle)
y = 0.3665x - 0.1144
R2 = 0.9993
Kinetic frictional force (N)
1.7
1.68
1.66
1.64
1.62
1.6
1.58
1.56
1.54
4.5
4.6
4.7
4.8
4.9
5
Normal force (N)

$$\mu_k = 0.3665 .$$


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
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + -14.000 t + 95.000 t^2
Y - Fit Equation
u(t)=5.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-14.000 + 190.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t)=-20.000 + 190.000t
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

TA Lab Evaluations
Physics 1301 Lab 3

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

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?
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:

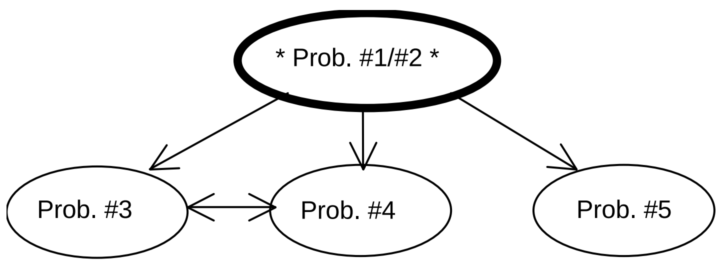
Was the room kept neat and clean by your class and other classes? yes / no
Was the equipment functioning properly? Could you fix it? yes / no
Any other comments regarding the room and equipment?

____
____
____

Laboratory IV: Conservation of Energy

General Teaching Tips

1. 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.
2. This lab is designed to study energy NOT momentum, even though the problems deal with collisions. **DO NOT** discuss momentum. Momentum is covered in Lab V.
3. **Energy efficiency** is defined at the beginning of Lab IV, 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. **Lab IV#2 is done is the Sample Lab Report Appendix. Do not assign it for lab report!!!**
4. Remember to make sure that every group member gets a turn at 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.



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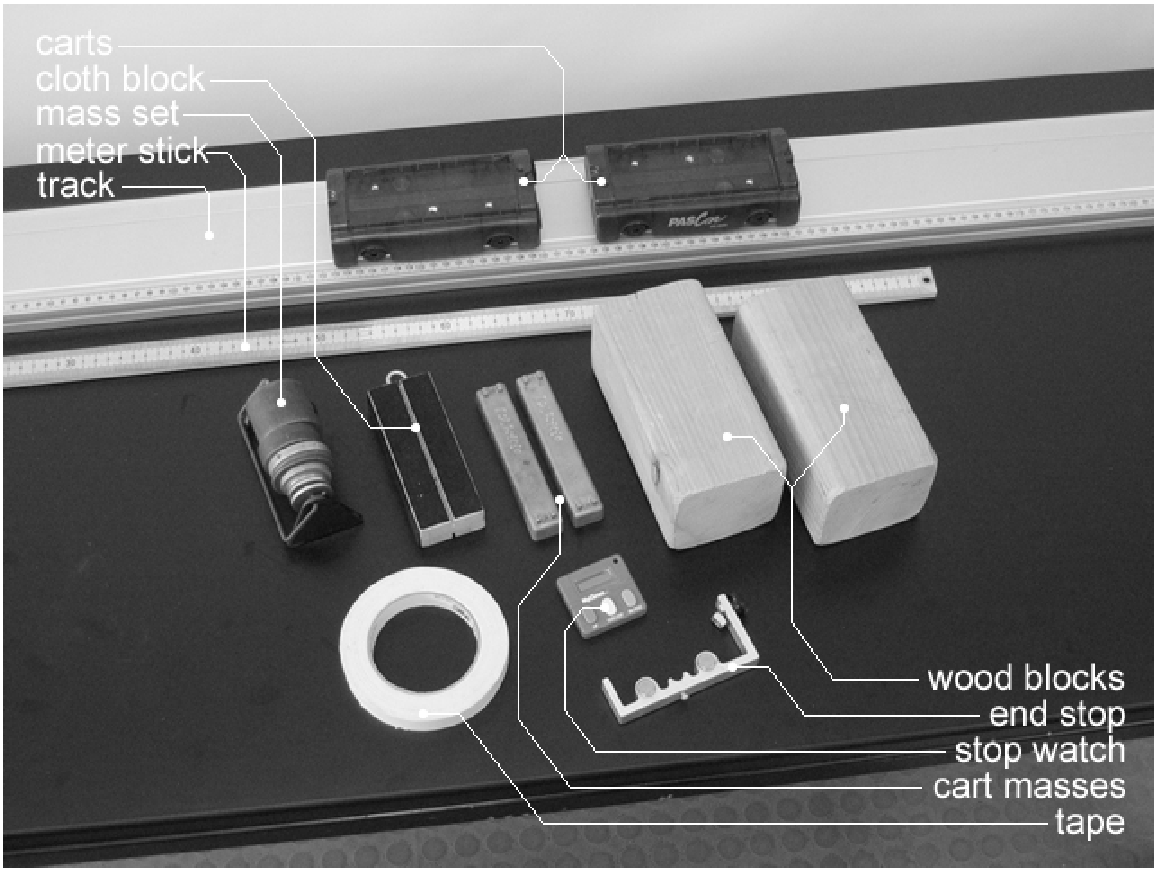
By the end of this lab students should be able to:

- 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.

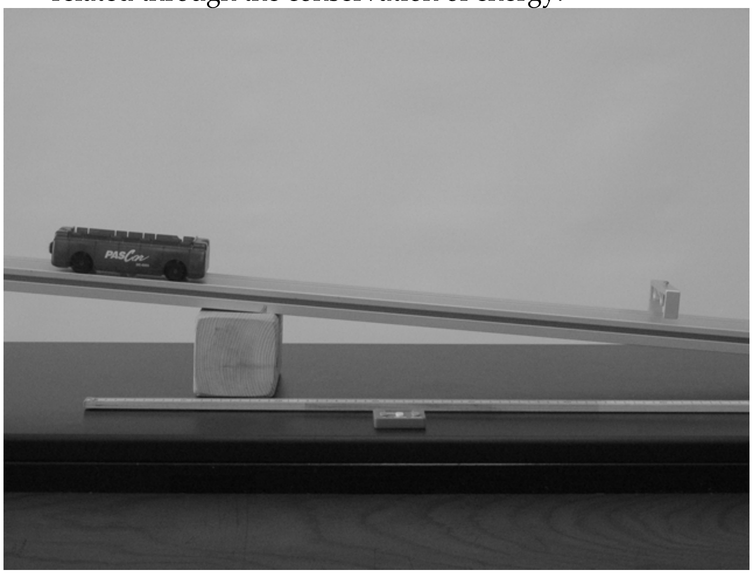
Equipment List:


carts
cloth block
mass set
meter stick
track
wood blocks
end stop
stop watch
cart masses
tape

Problem #1 and Problem #2: Kinetic Energy and Work

Purpose:

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



Teaching Tips:

1. This problem is a simple application of energy conservation that only requires the students to understand the concepts of kinetic energy and work.
2. **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.
3. Remember to warn your students to avoid having their carts jump off the track.
4. 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.
5. 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.
6. 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:

1) Problem #1

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

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

2) **Problem #2. (Lab IV#2 is done is the Sample Lab Report Appendix. Do not assign it for lab report !!!)**

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

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.

<u>Correction for efficiency of problem #2:</u>

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)

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

Kinetic energy just before collision

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

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

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:

1) Problem #1

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

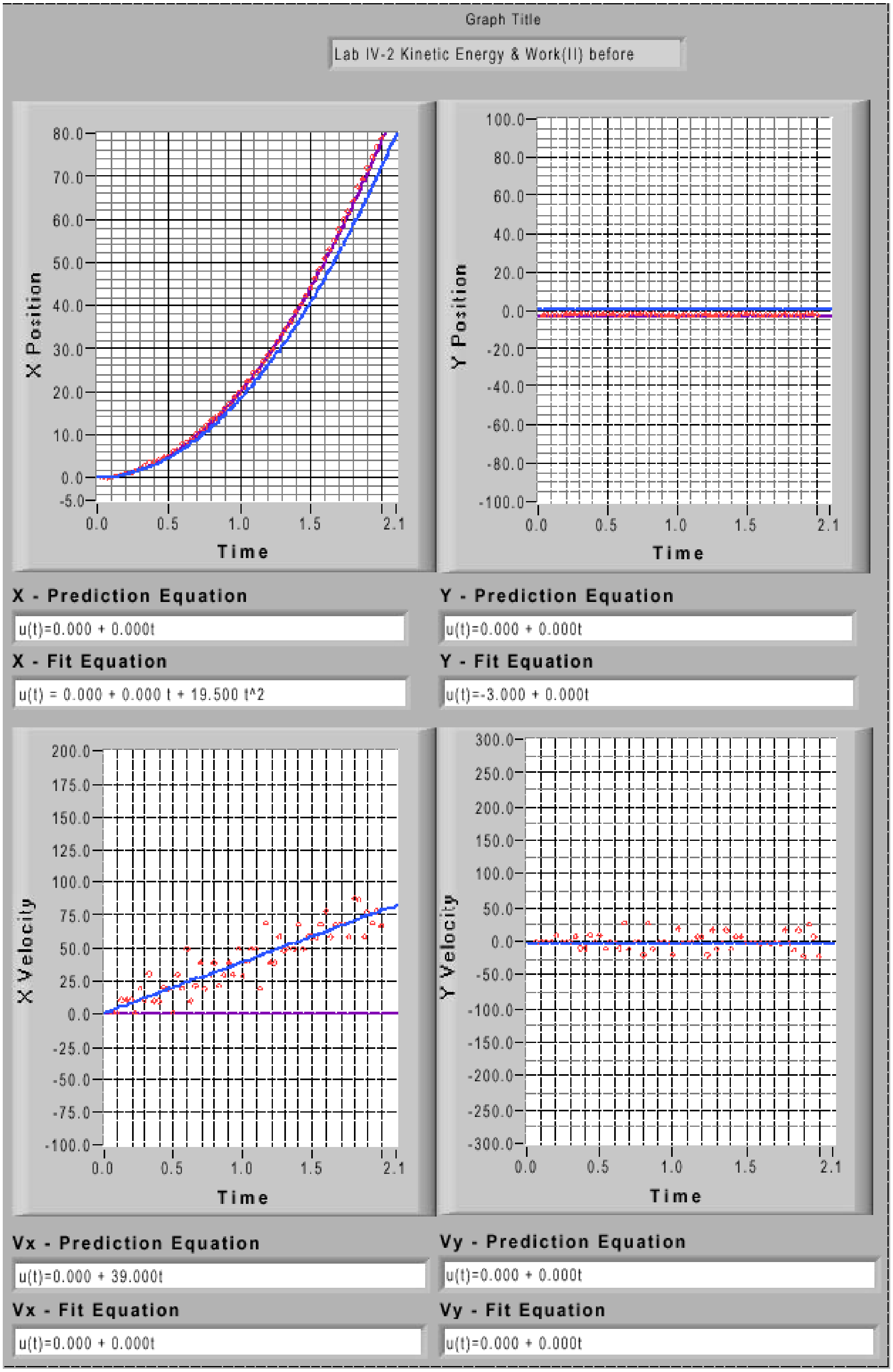
Efficiency=0.96.

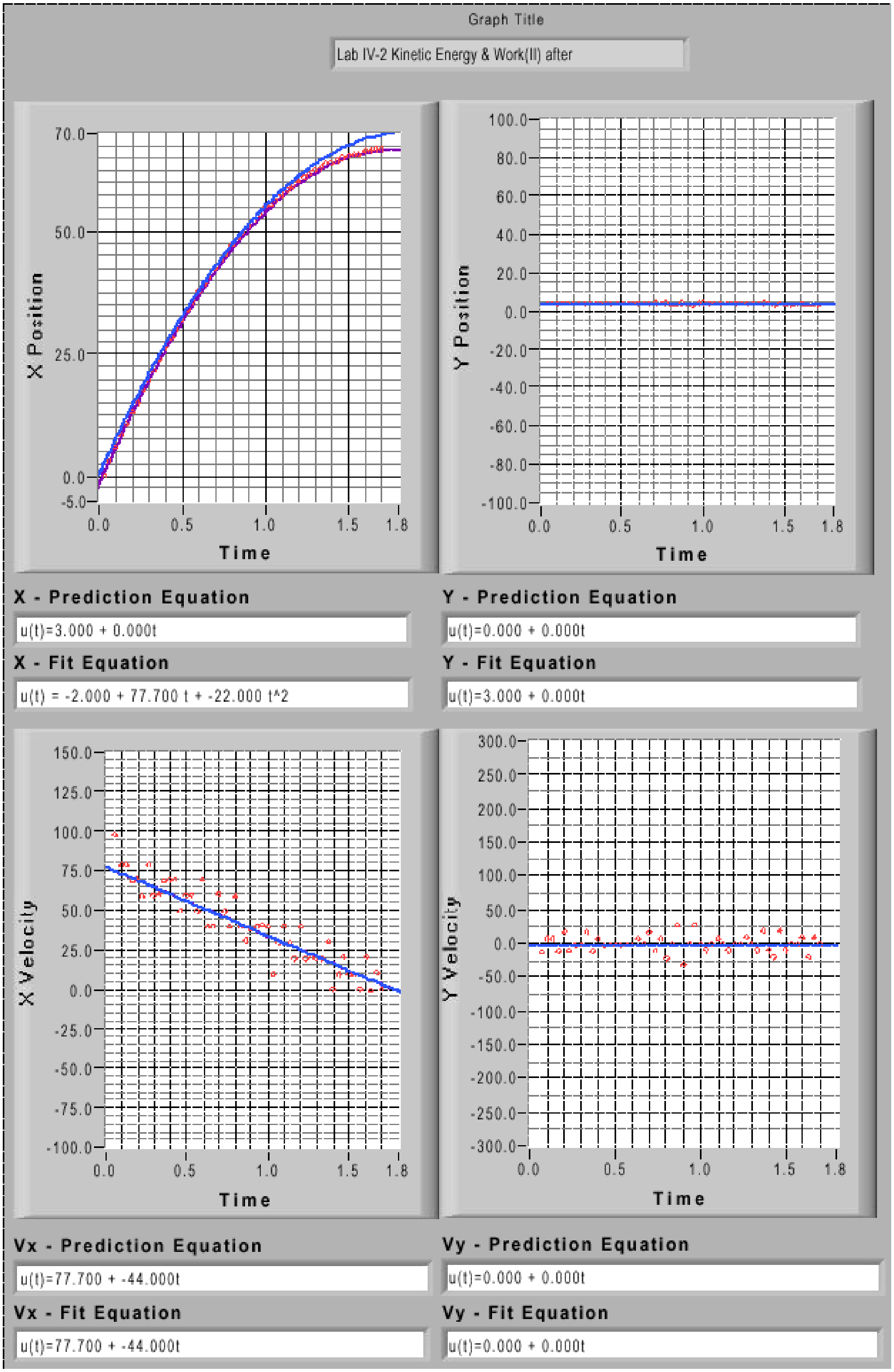
2) Problem #2

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 that the efficiency of bumper is close to 1.

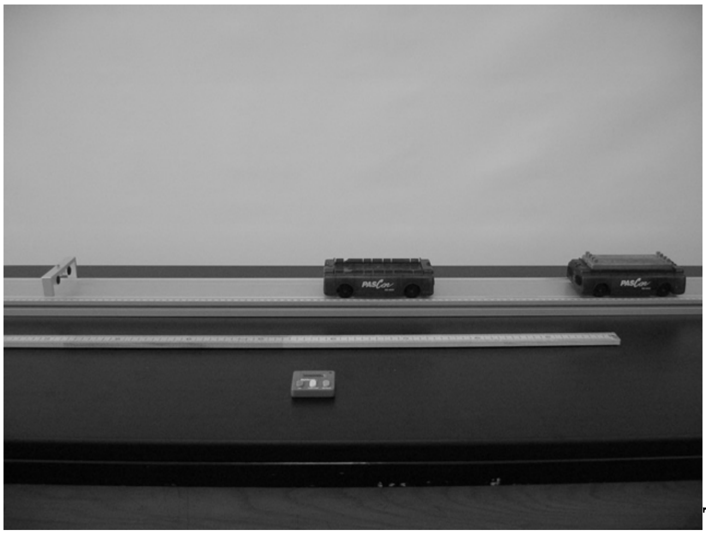

Graph Title
Lab IV-2 Kinetic Energy & Work(II) before
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.000 t + 19.500 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - 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
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) = -2.000 + 77.700 t + -22.000 t^2
Y - Fit Equation
u(t)=3.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=77.700 + -44.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t)=77.700 + -44.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

Problem #3 and #4: Energy and Collisions

Purpose:

- To help students see how kinetic energy is related to the energy of a system using conservation of energy in different collisions.



Teaching Tips:

1. **Do not lecture about momentum** and do not ask your students to solve the collision problems in terms of momentum. Conservation of energy is all that is needed here.
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. Make sure your students catch the carts before they hit the end stops.
5. The students need to analyze movies more than once to determine all velocities involved.
6. Encourage students to do the analysis efficiently. The point is not to analyze movies but to use the resulting velocities for other things.
7. 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.

Prediction:

Problem #3: From most to least efficient: $m_A > m_B$, $m_A = m_B$, $m_A < m_B$

Problem #4: Efficiencies should all be much higher for objects that bounce apart compared to sticking together.

Warm up questions:

Problem #3: $$\text{Eff} = \frac{(m_1 + m_2)v'^2}{m_1 v^2}$$

Problem #4: $$\text{Eff} = \frac{m_1 v_1'^2 + m_2 v_2'^2}{m_1 v^2}$$

Problem #3 & #4: $$E_d = KE_i\left(1 - Eff\right)$$

Here m_1 is the initially moving mass, m_2 is the mass initially at rest, the *v*'s are the respective final velocities, E_d is the energy dissipated, KE_i is the initial kinetic energy, and *Eff* is the efficiency.

Sample Data: a sample of the graphs are included**Problem 3: (stick together)**

1) $m_1 = m_2$
Mass of cart 1: m_1 = 503.60g
Mass of cart 2: m_2 = 503.12g
Initial velocity of cart 1: v = 52.70 cm/s
Final velocity of both carts: v' = 26.50 cm/s
Energy efficiency: Eff = 0.51
Energy dissipated E_d = 3.46J

2) $m_1 > m_2$
Mass of cart 1: m_1 = 753.80g
Mass of cart 2: m_2 = 252.92g
Initial velocity of cart 1: v = 43.10 cm/s
Final velocity of both carts: v' = 32.50 cm/s
Energy efficiency: Eff = 0.76
Energy dissipated E_d = 1.68J

3) $m_1 < m_2$
Mass of cart 1: m_1 = 252.80g
Mass of cart 2: m_2 = 753.92g
Initial velocity of cart 1: v = 91.00 cm/s
Final velocity of both carts: v' = 23.80 cm/s
Energy efficiency: Eff = 0.27
Energy dissipated E_d = 7.62J

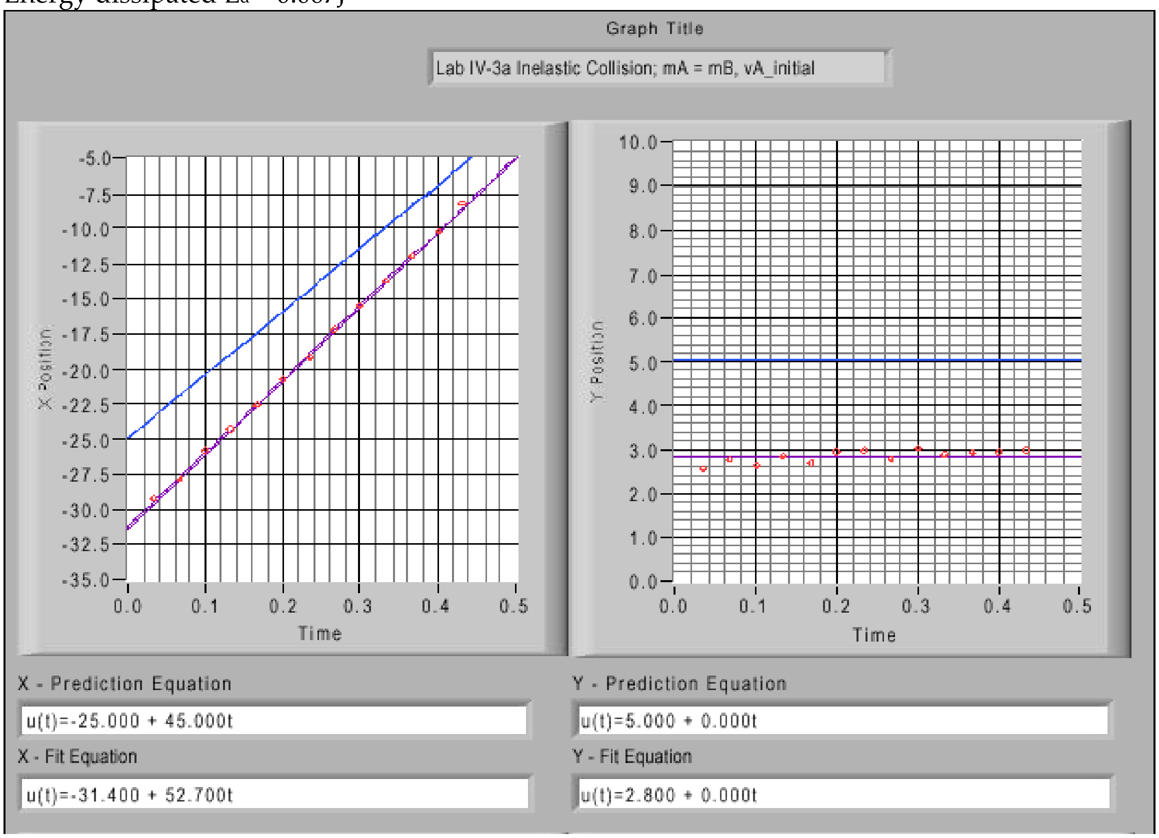
Problem 4: (bounce apart)

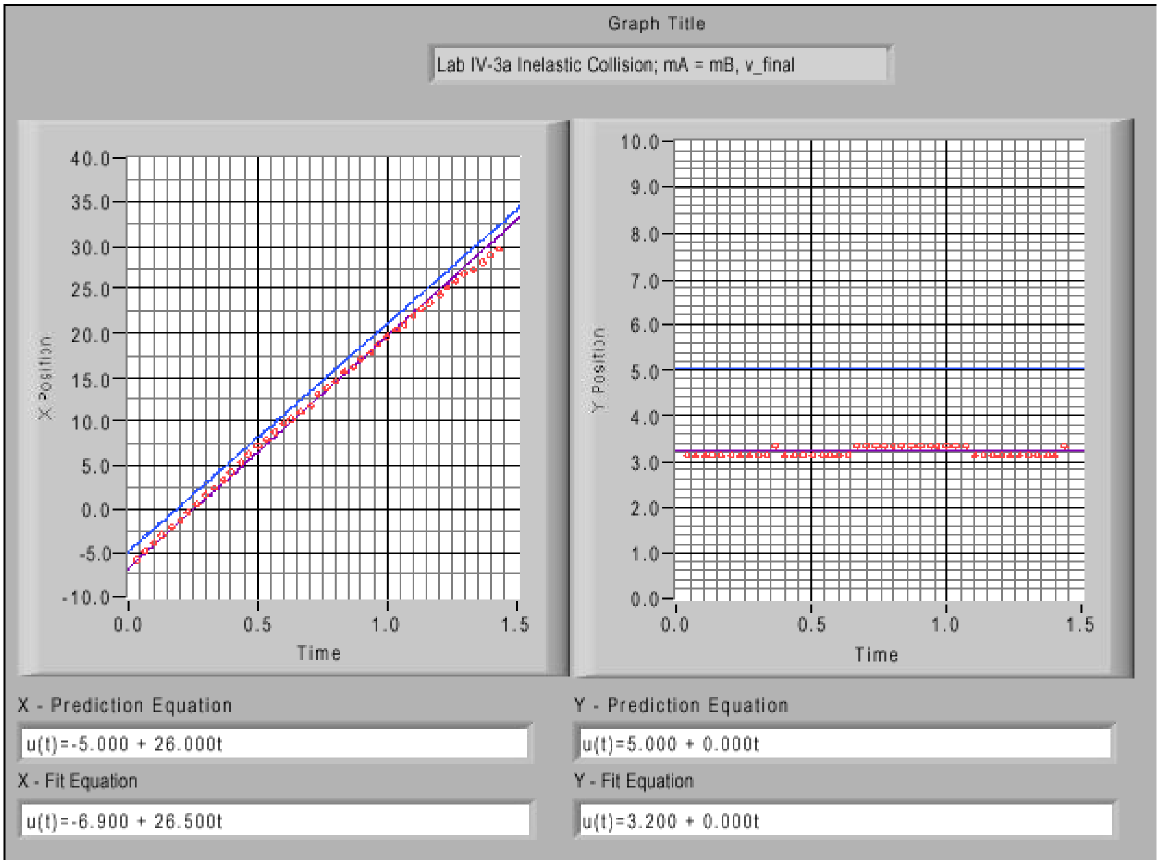
1) $m_1 = m_2$
Mass of cart 1: m_1 = 503.60g
Mass of cart 2: m_2 = 503.12g
Initial velocity of cart 1: v = 61.20 cm/s
Final velocity of cart 1: v_1' = 0.00 cm/s
Final velocity of cart 2: v_2' = 60.30 cm/s
Energy efficiency: Eff = 0.97
Energy dissipated E_d = 0.28J

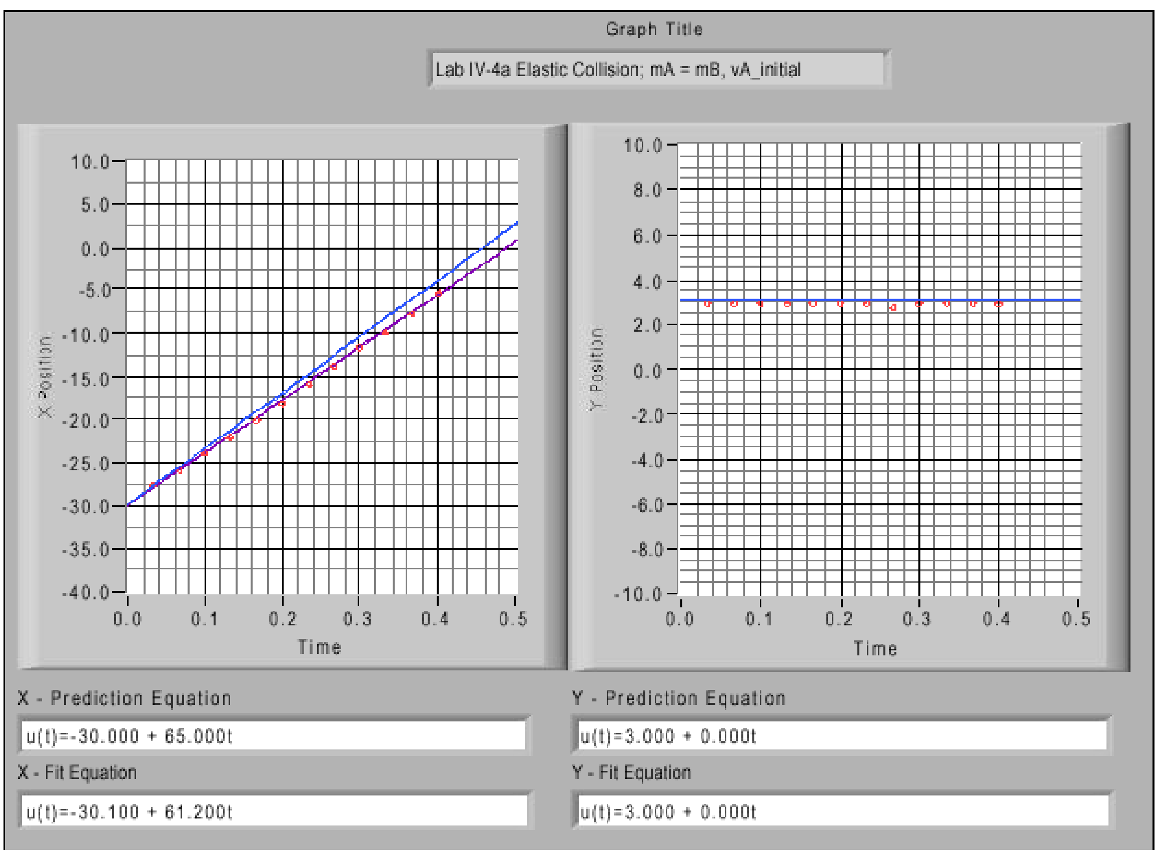
2) $m_1 > m_2$
Mass of cart 1: m_1 = 753.80g
Mass of cart 2: m_2 = 252.92g
Initial velocity of cart 1: v = 62.80 cm/s

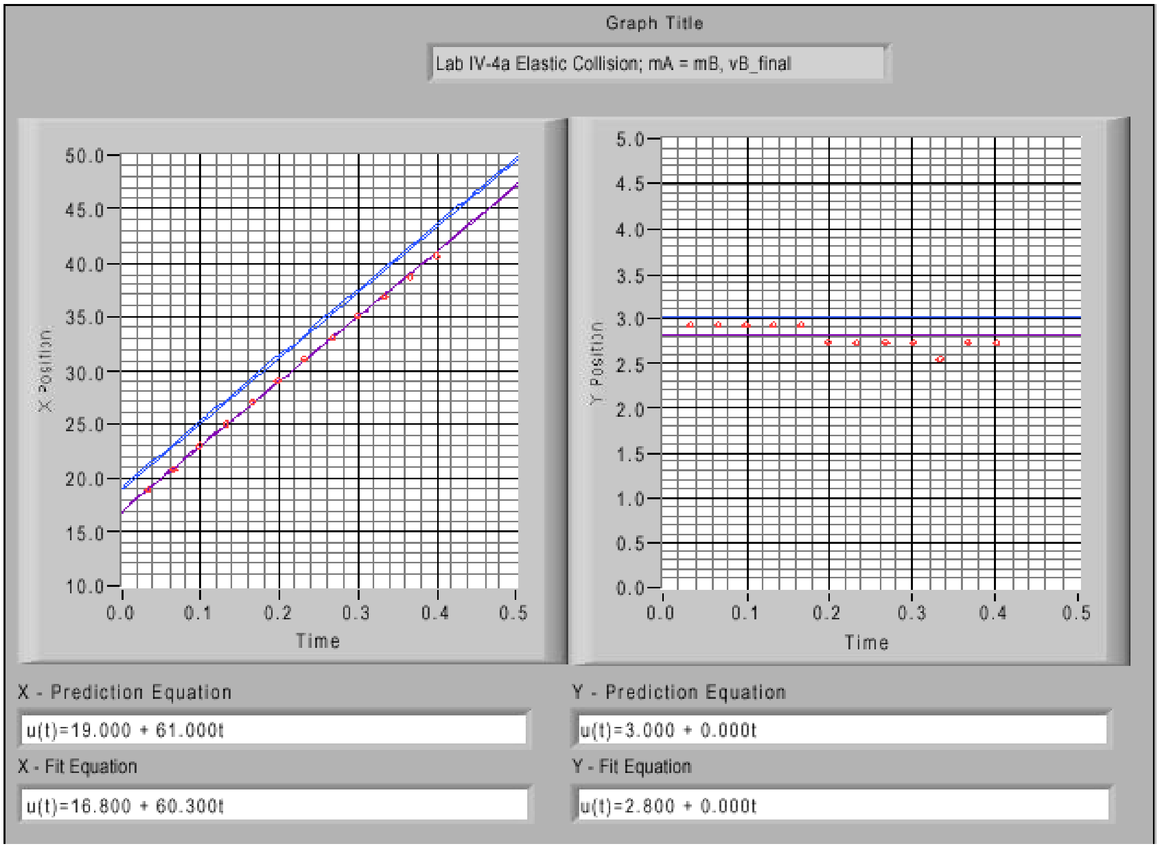
Final velocity of cart 1: $v_1' = 32.80$ cm/s
Final velocity of cart 2: $v_2' = 92.40$ cm/s
Energy efficiency: Eff = 1.00
Energy dissipated $E_d = 0.013$J

3) $m_1 < m_2$
Mass of cart 1: $m_1 = 252.80$g
Mass of cart 2: $m_2 = 753.92$g
Initial velocity of cart 1: $v = 51.70$ cm/s
Final velocity of cart 1: $v_1' = -25.50$ cm/s
Final velocity of cart 2: $v_2' = 25.70$ cm/s
Energy efficiency: Eff = 0.98
Energy dissipated $E_d = 0.067$J




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

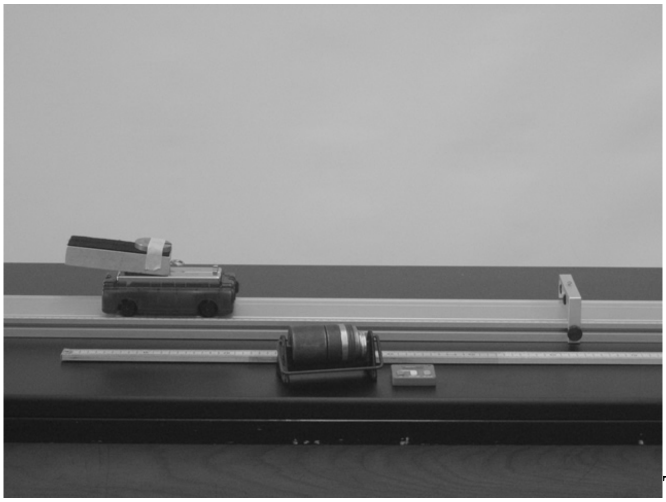

Graph Title
Lab IV-4a Elastic Collision; mA = mB, vA_initial
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-30.000 + 65.000t
X - Fit Equation
u(t)=-30.100 + 61.200t
Y - Prediction Equation
u(t)=3.000 + 0.000t
Y - Fit Equation
u(t)=3.000 + 0.000t


Graph Title
Lab IV-4a Elastic Collision; mA = mB, vB_final
X Position
Y Position
Time
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

Problem #5: 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.



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 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.

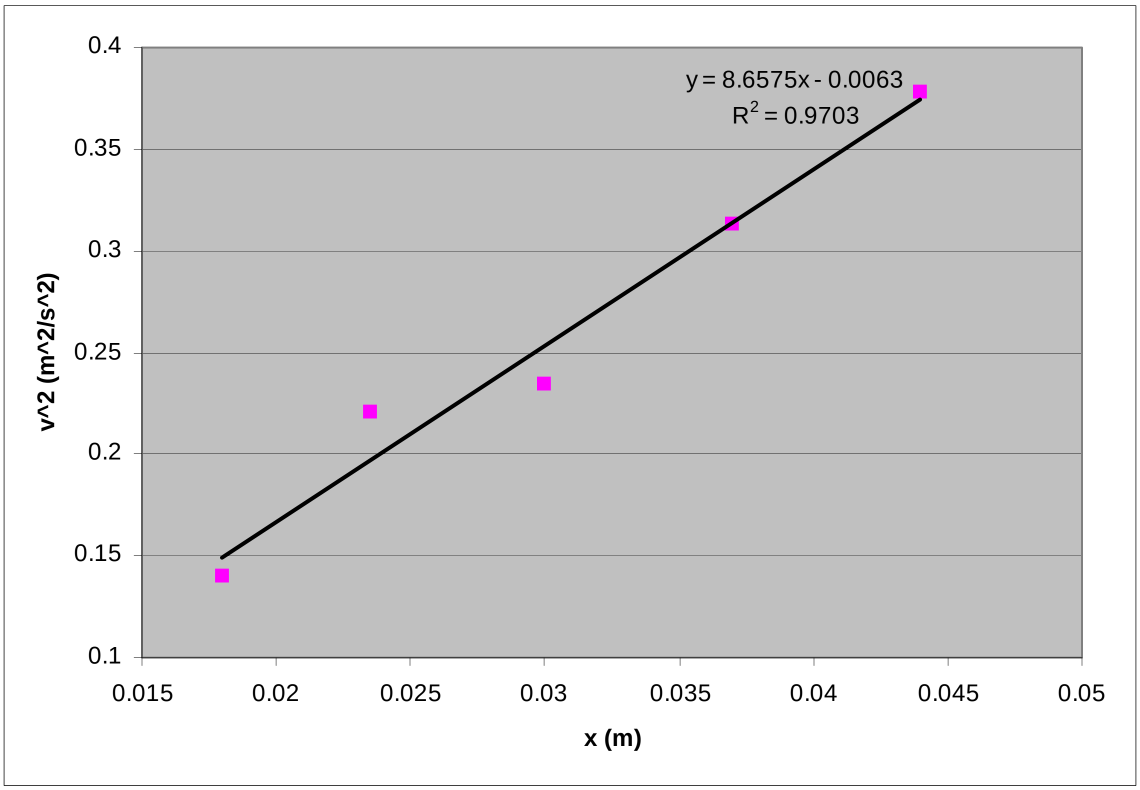
Sample Data:

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

Data Table of distance X vs. Velocity

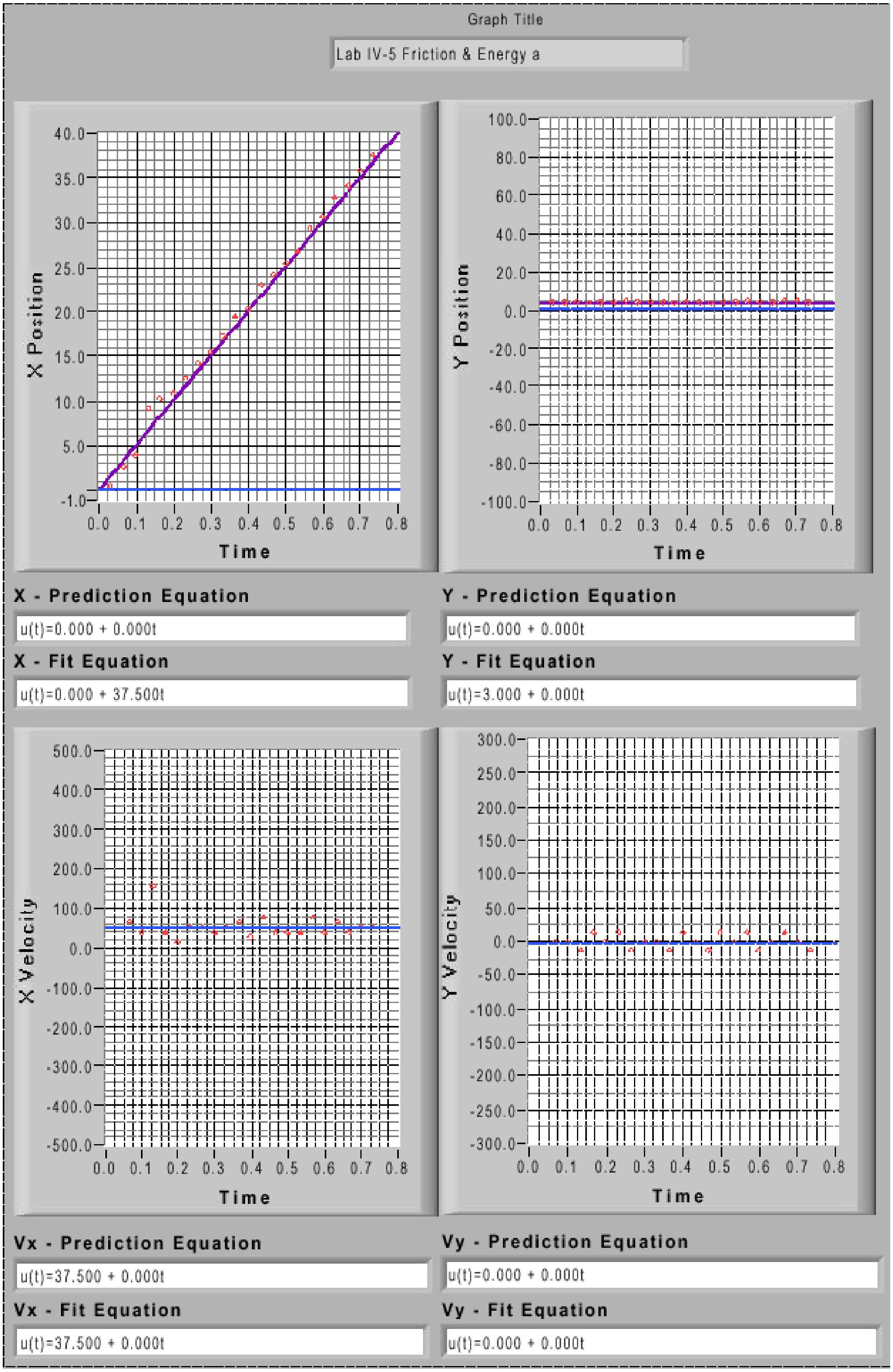
X (cm)	1.8	2.35	3.00	3.70	4.40
V (cm/s)	37.5	47.0	48.5	56.0	61.5

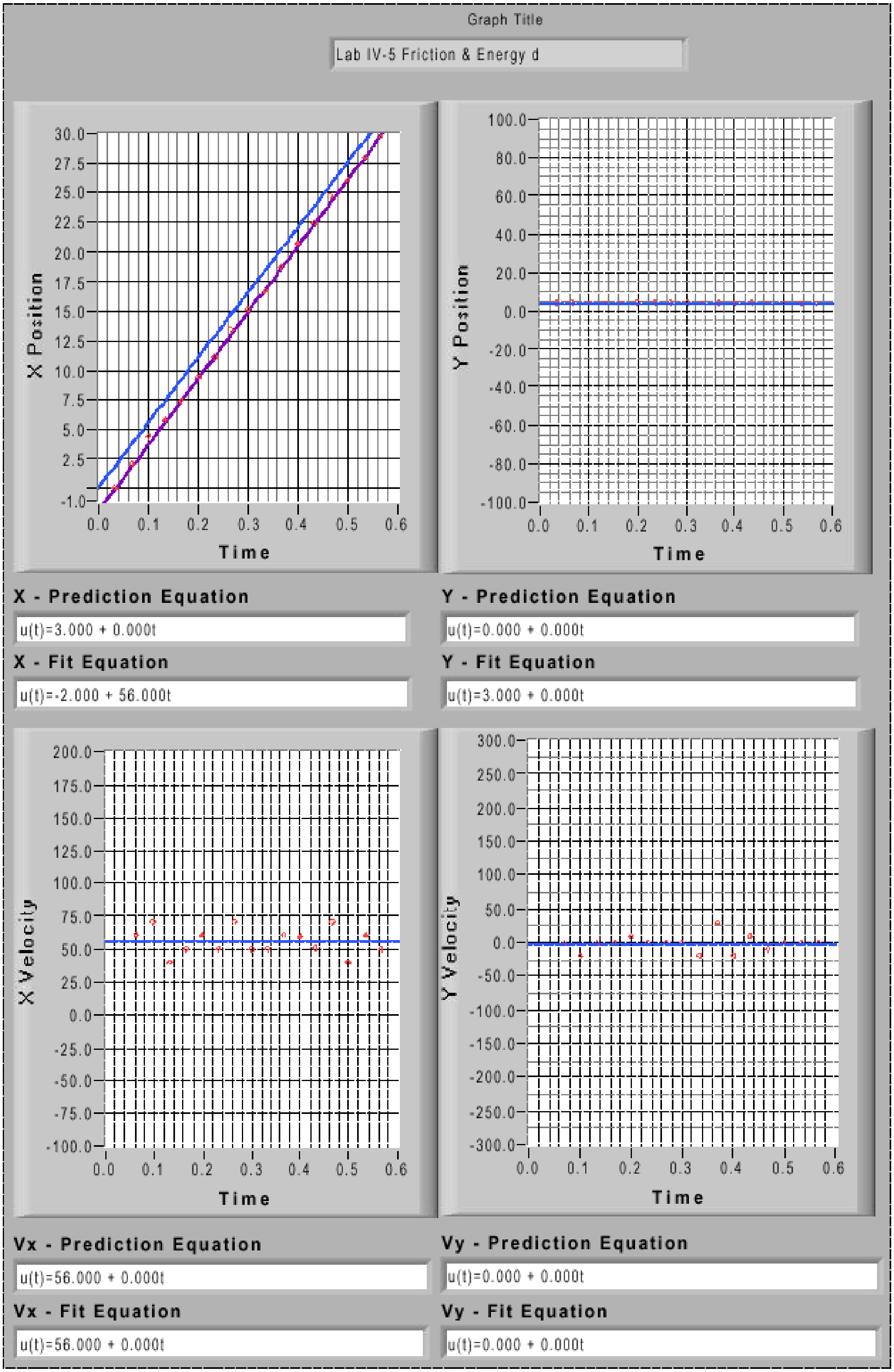
Fit line for X vs. V^2



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 4

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

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Students:

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

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

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TA:

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

Why or why not?

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Results:

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

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

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Lab Room:

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

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

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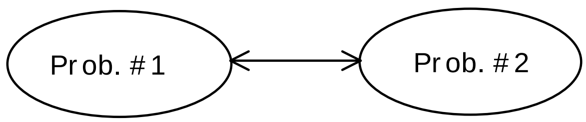
Laboratory V:
Conservation of Energy and Momentum

General Teaching Tips

1. 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, then they should be able to complete these problems.

2. These problems deal with the same situations found in Lab IV. In fact, the students should recognize, on their own, that they do not need to take any new data. Now the students should apply the concept of conservation of momentum in addition to conservation of energy.



Things to Remember:

- Use the clipboard in the lab room to report any problems on the equipments.
- The printer may not print the correct equations. Remind the students to write down the equations in the prediction and fitting steps before they proceed to the next step.

By the end of this lab students should be able to:

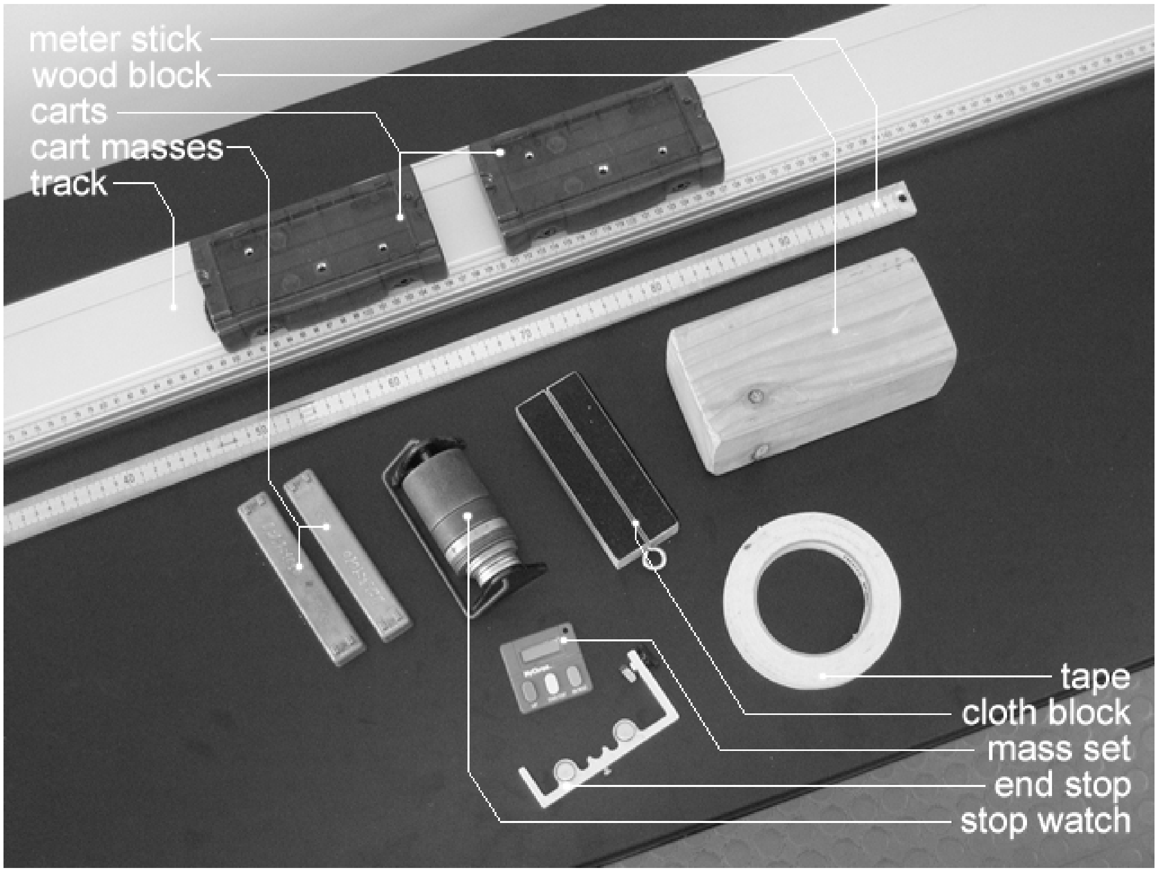
- Use the principles of conservation of energy and of momentum together as a means of describing the behavior of a system.

Things to check out before teaching the lab:

Since this is the same equipment as for the previous lab, you should be all prepared.

- Check every wheel for every plastic cart to see if the wheel can last rotating at least two seconds by a gentle push.

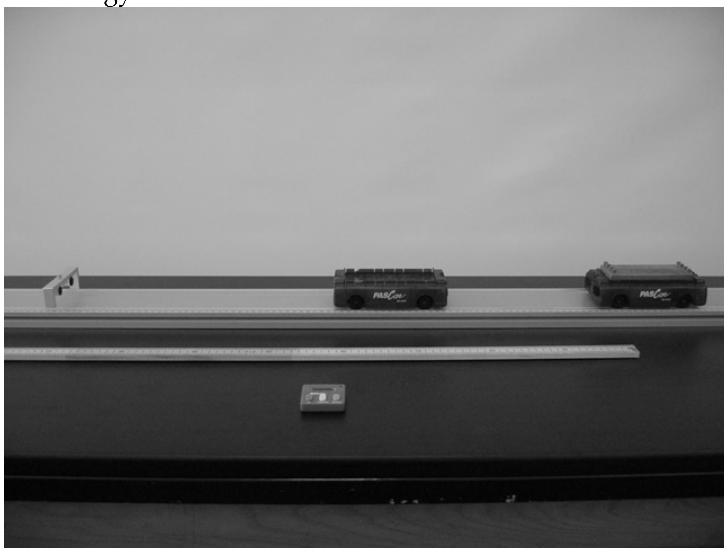
Equipment List:



Problems #1 and #2: Inelastic and Elastic Collisions

Purpose:

- To use the concept of conservation of momentum while reinforcing the difference between energy and momentum.



Teaching Tips:

1. The solution to the prediction equation for Problem #2 is a quadratic for both of the final velocities 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. Students don't need to take any additional data if they have already done the corresponding problem in the previous lab. However, they may want to take the data again. Let them.
3. Do not let a single student monopolize either the computer or the equipment.

Difficulties and 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:

Problem 1: $$v' = \frac{m_1 v_1}{m_1 + m_2}$$

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.

Problem 2:

$$v_1' = \frac{\frac{m_1}{m_2} \pm \sqrt{Eff\,(1 + m_1/m_2) - m_1/m_2}}{(1 + m_1/m_2)} \cdot v_1$$

$$v_2' = \frac{1 \mp \sqrt{1 - (m_1/m_2 + 1)(1 - Eff\,)}}{(1 + m_2/m_1)} \cdot v_1$$

where m_1 is the mass of the cart1 initially in motion, m_2 is the mass of the cart2 initially at rest, v_1 is the initial velocity of cart1, v_1' is the final velocity of cart1, v_2' is the final velocity of cart2, and *Eff* is the efficiency of the magnets bumper at the end side of carts. Of course things are simplified if you can use previous results to say that the efficiency is approximately one

Sample Data:

The data for these two problems are the same data for Laboratory IV, Problem 3 and Problem 4. For the computer printouts for all measured velocities, see Sample Data of Laboratory IV, Problem 3 and Problem 4.

Problem 1: (stick together)

1) $m_1 = m_2$
Mass of cart 1: m_1 = 503.60g; Mass of 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

2) $m_1 > m_2$
Mass of cart 1: m_1 = 753.80g; Mass of 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

3) $m_1 < m_2$
Mass of cart 1: m_1 = 252.80g; Mass of 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

Problem 2: (bounce apart)
1) $m_1 = m_2$
Mass of cart 1: m_1 = 503.60g; Mass of cart 2: m_2 = 503.12g
Initial velocity of cart 1: v = 61.20 cm/s
Energy efficiency: Eff = 0.97 (from Lab IV-4)

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 of cart 1: m_1 = 753.80g; Mass of cart 2: m_2 = 252.92g
Initial velocity of cart 1: v = 62.80 cm/s
Energy efficiency: Eff = 1.00 (from Lab IV-4)
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 of cart 1: m_1 = 252.80g; Mass of cart 2: m_2 = 753.92g
Initial velocity of cart 1: v = 51.70 cm/s
Energy efficiency: Eff = 0.98 (from Lab IV-4)
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

TA Lab Evaluations
Physics 1301 Lab 5

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

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____

Students:

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

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

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____

TA:

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

Why or why not?

____

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____

Results:

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

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

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Lab Room:

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

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

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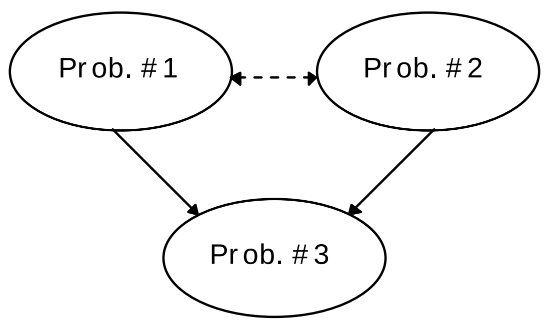
Laboratory VI:
Rotational Kinematics

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.



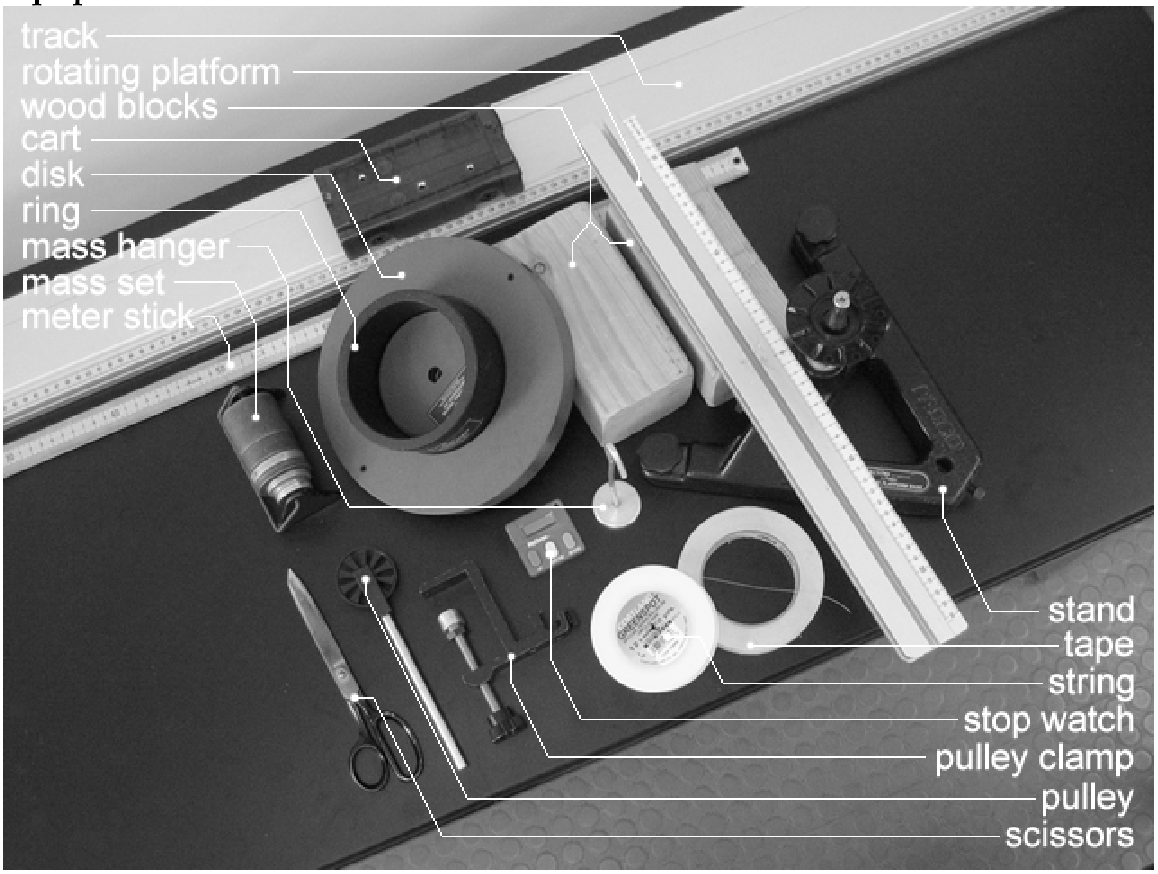
Things your students should know by the end of this lab:

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

Things to check out given fifteen minutes with the equipment:

- 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).

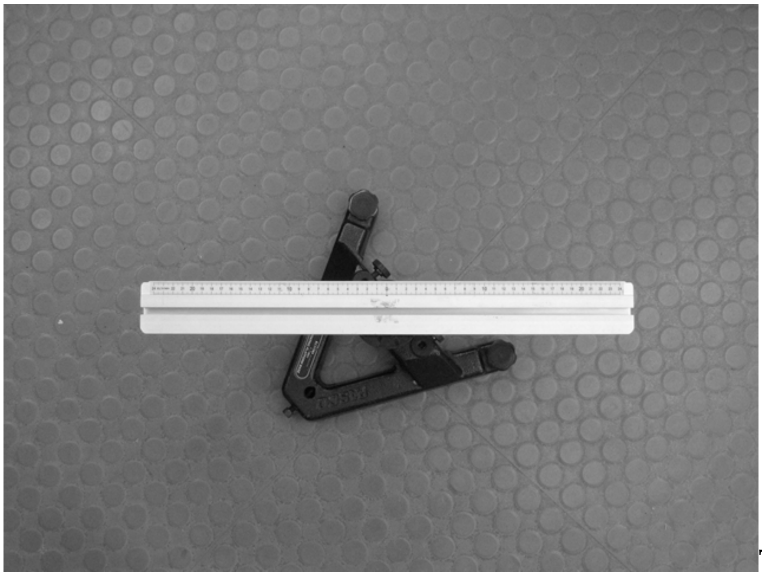
Equipment List:



Problem #1: Angular Speed 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.



Teaching Tip:

1. 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.
2. 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.
3. 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:

$$v(r) = \omega r \ ,$$

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

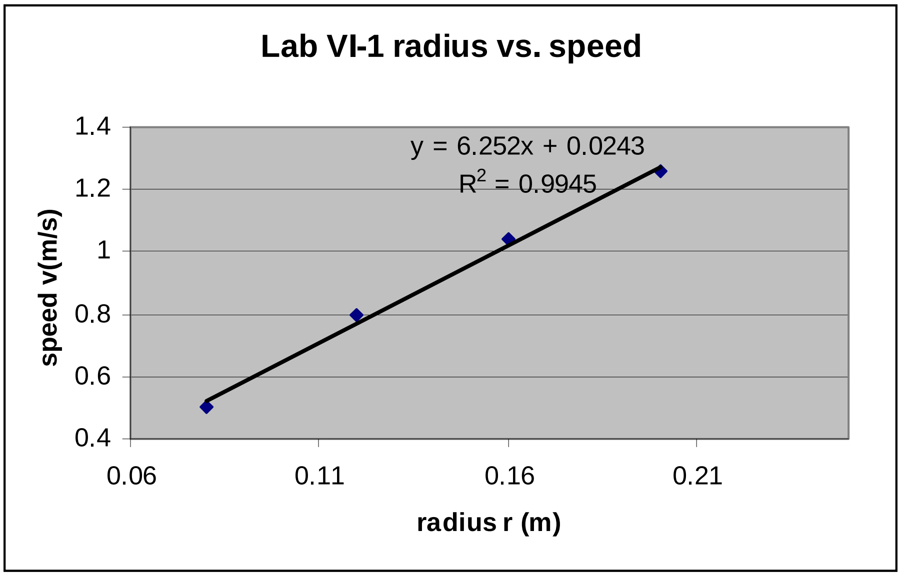
where r is the distance of the point from the axis of rotation, v is its linear speed, a is its acceleration and ω is its angular speed.

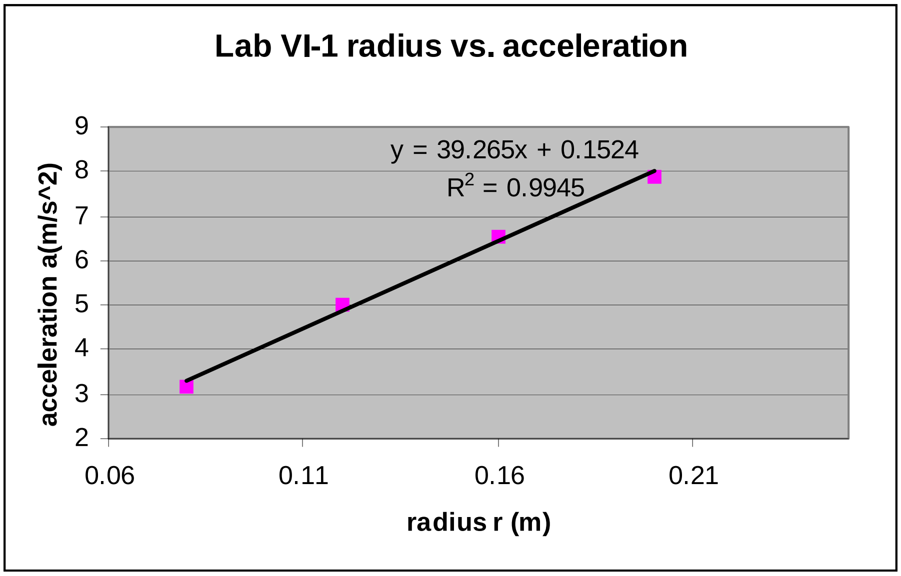
Sample Data:

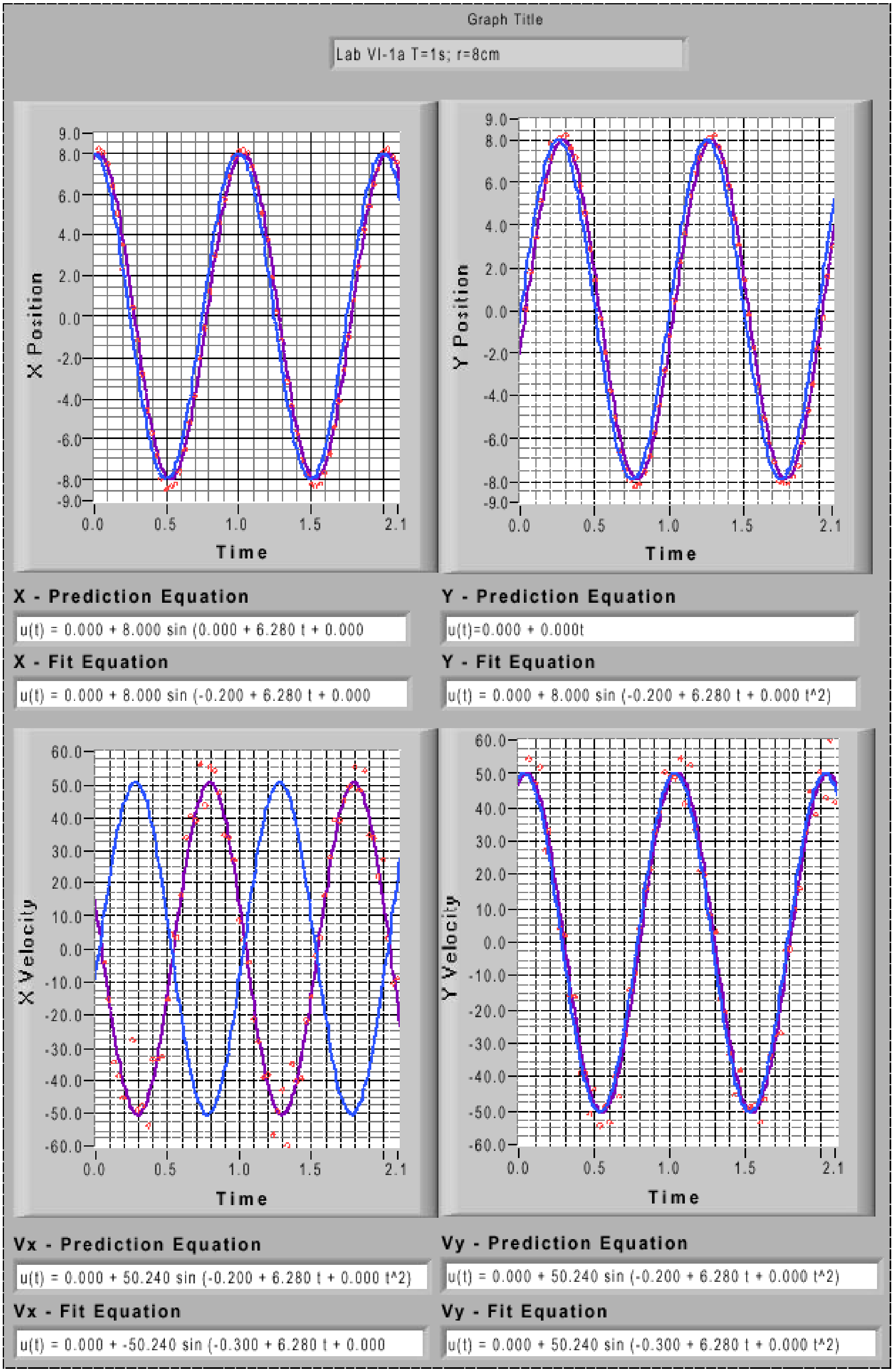
The printouts for the measurements of all velocities are included at the end of the following sample data.

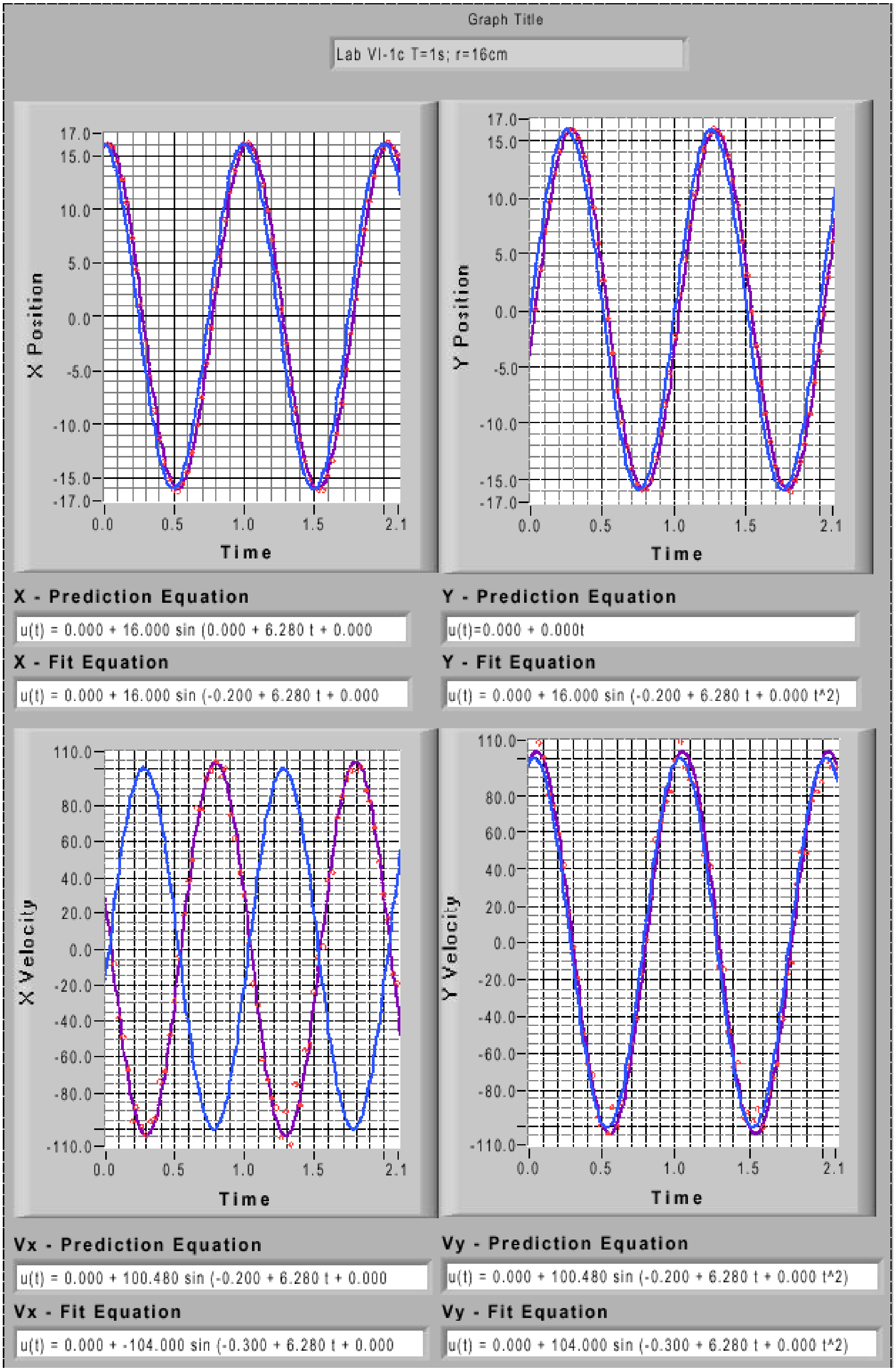
$\omega = 6.28\ s^{-1}$

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





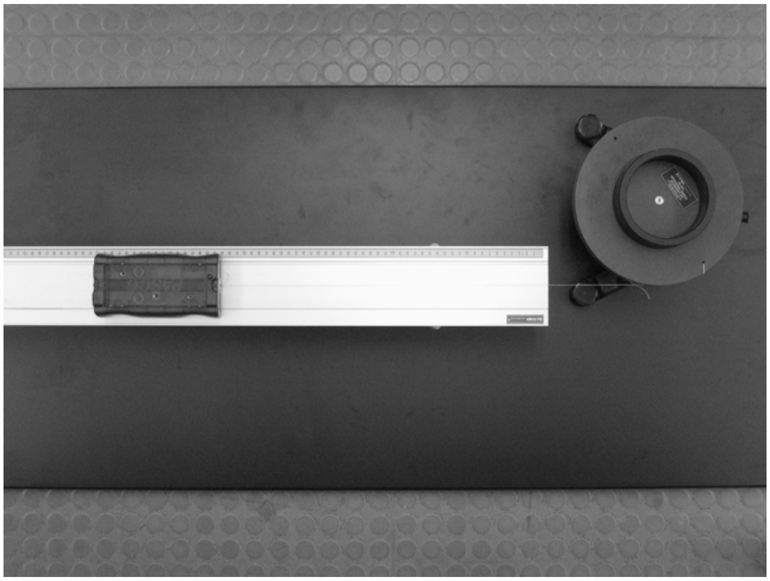

Graph Title
Lab VI-1a T=1s; r=8cm
X Position
Time
Y Position
Time
X - Prediction Equation
u(t) = 0.000 + 8.000 sin (0.000 + 6.280 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 8.000 sin (-0.200 + 6.280 t + 0.000
Y - Fit Equation
u(t) = 0.000 + 8.000 sin (-0.200 + 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
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 16.000 sin (-0.200 + 6.280 t + 0.000
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
Vy - Prediction Equation
u(t) = 0.000 + 100.480 sin (-0.200 + 6.280 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -104.000 sin (-0.300 + 6.280 t + 0.000
Vy - Fit Equation
u(t) = 0.000 + 104.000 sin (-0.300 + 6.280 t + 0.000 t^2)

Problem #2: Rotation and Linear Motion at Constant Speed

Purpose:

To reproduce the relationship between the constant angular speed of an object and the linear speed which causes it.



Teaching Tips:

1. 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.

2. 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.

3. 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 II Problem 5 of this guide for an example of a "good movie."

4. Make sure that the string does not slip at the ring.

5. 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:

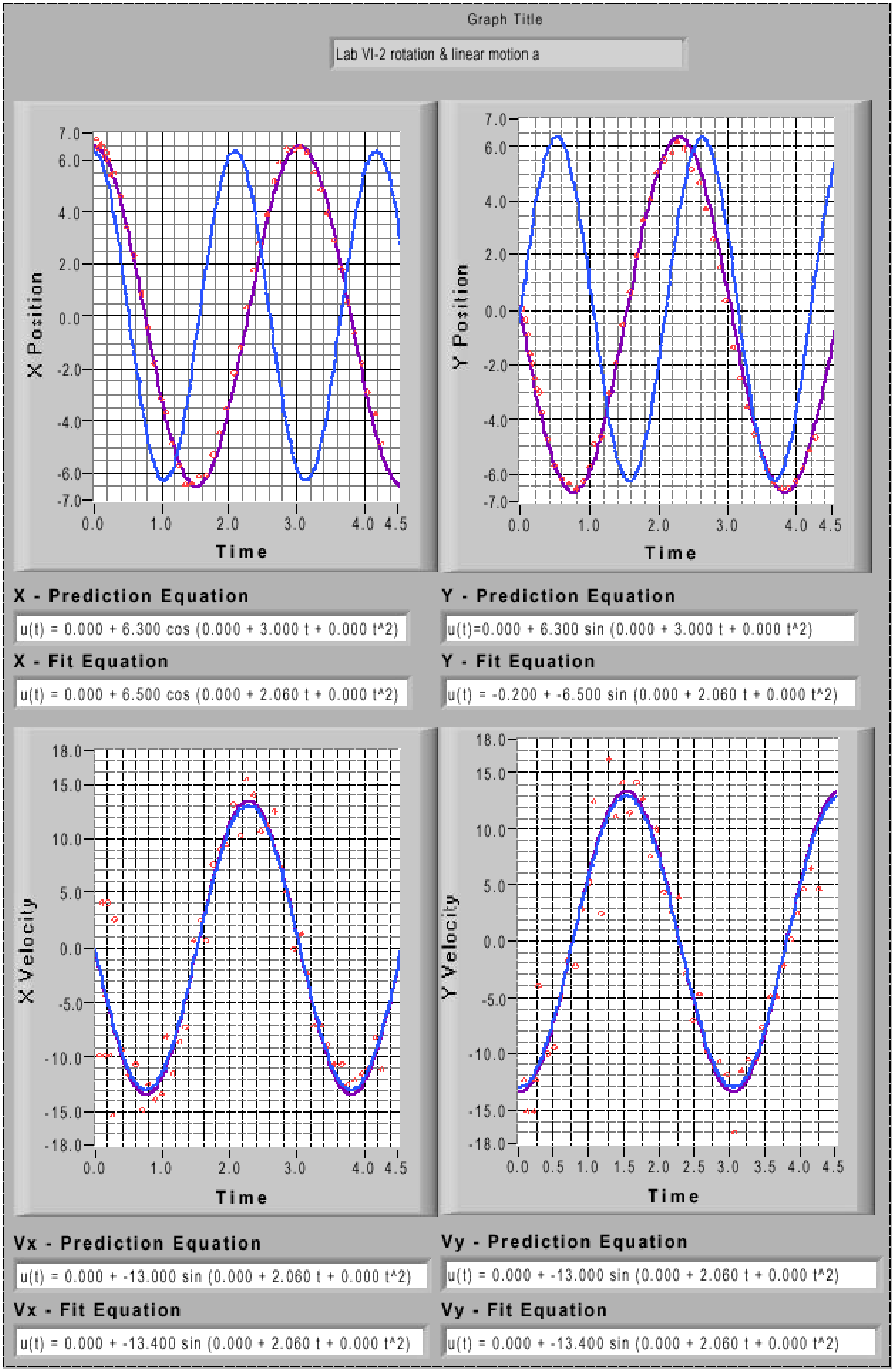
$$\omega = \frac{v}{r}$$

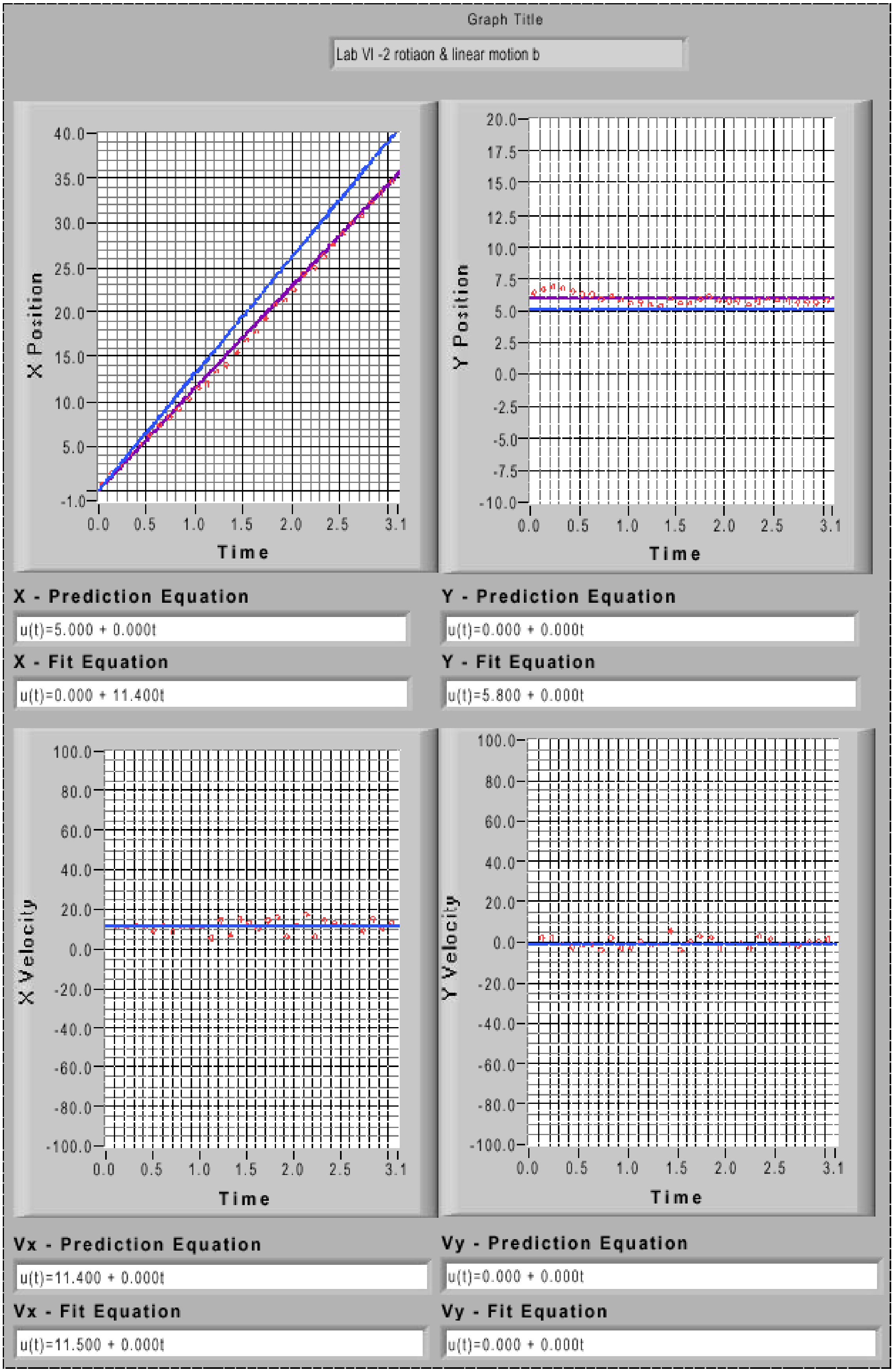
where ω is the angular speed of the disk, r is the radius of the ring, and v is the speed of the cart.

Sample Data:

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

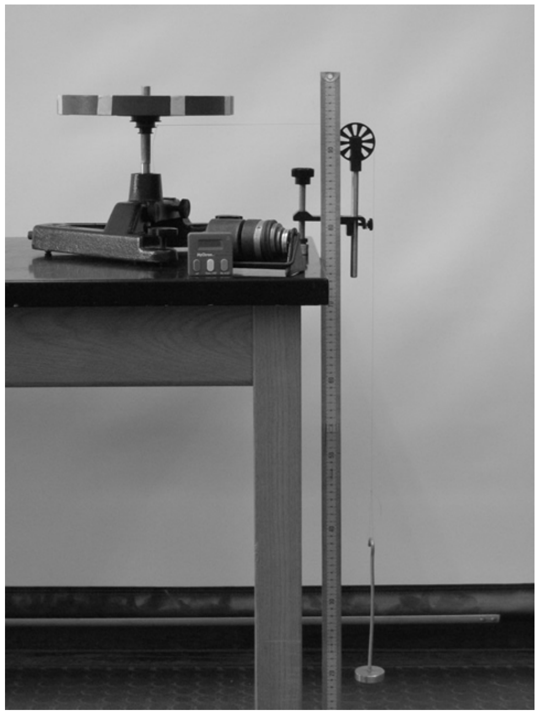
$r = 6.3$ (cm), $v = 11.5$ (cm/s),
predicted angular speed ω =1.825(s^{-1}),
measured angular speed $\omega = 2.06$ (s^{-1}).


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

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.



Teaching Tip:

1. 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.

2. 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.

3. 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 II Problem 5 of this guide for an example of a "good movie."

4. Make sure that the string does not slip at the spool.

5. 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.

6. 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:

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

where ◎ is the angular acceleration of the disk, a is the acceleration of the weight, and r is the radius of the spool.

Warm up questions:

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

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:

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

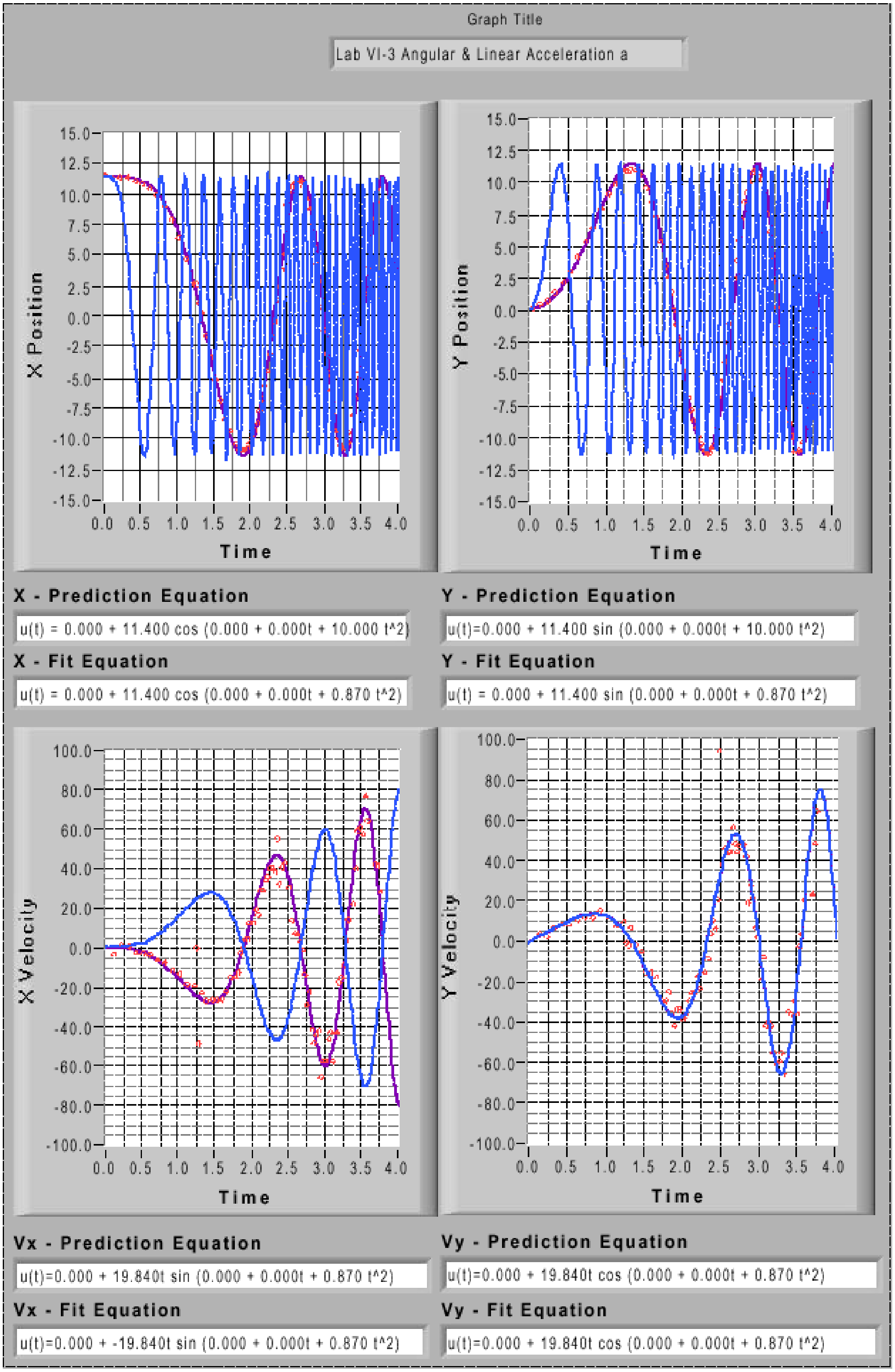
Comparing equations (A) and (B), the tangential acceleration is given by:

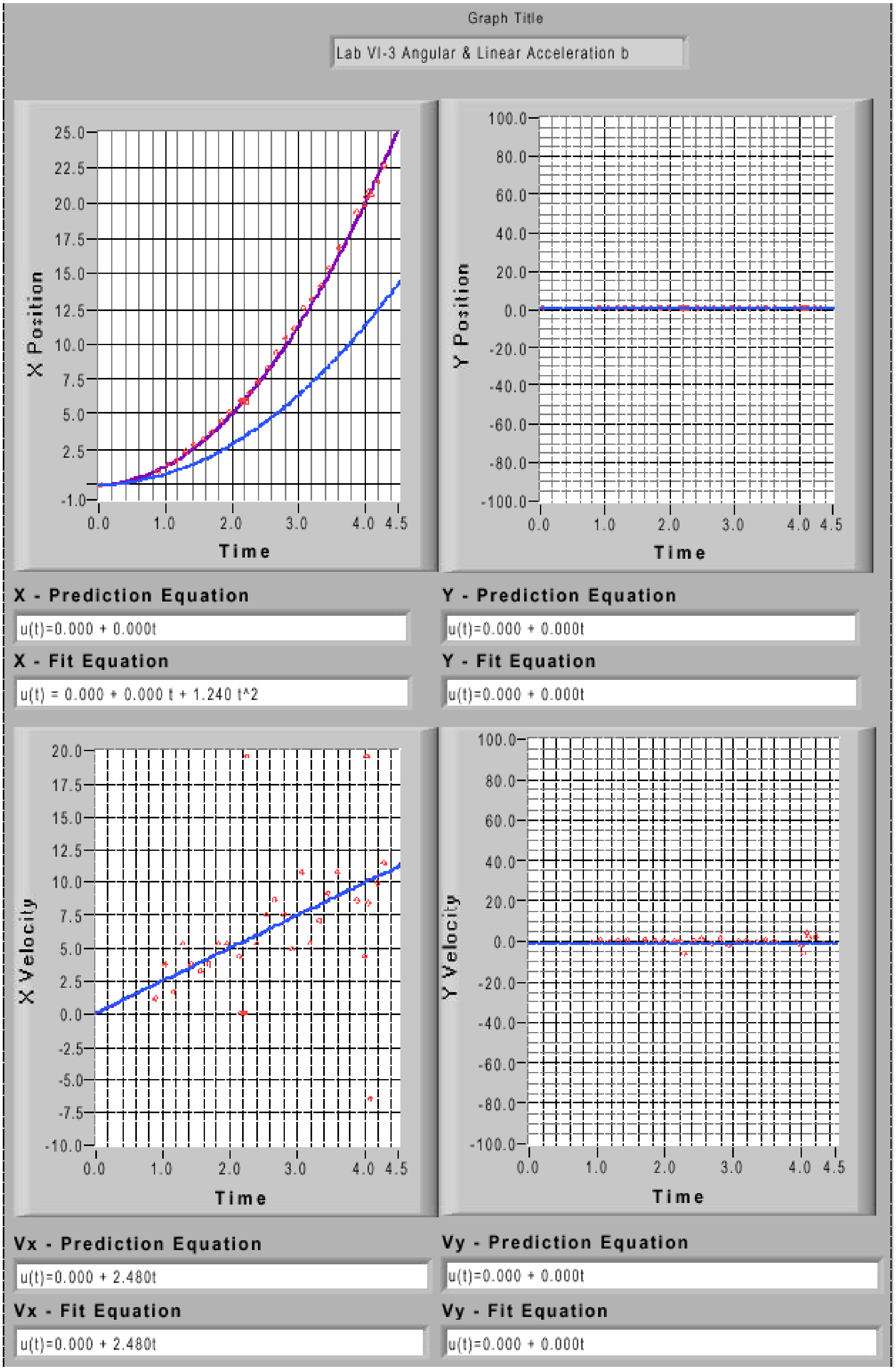
$$\boxed{a_T(t) = r\alpha}$$

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 6

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

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?

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? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

____

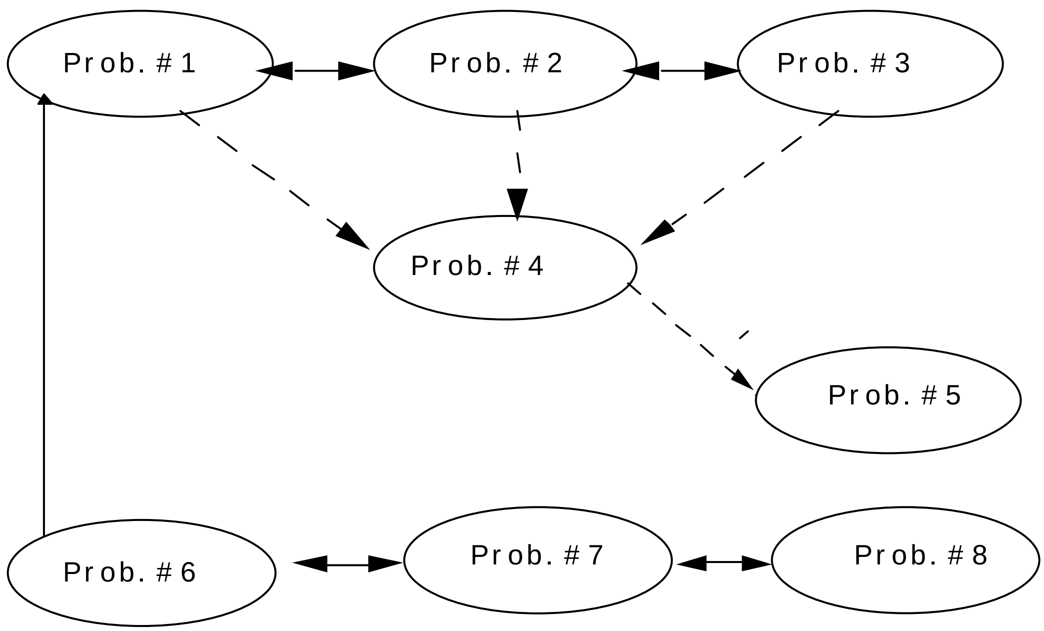
____

____

Laboratory VII:
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.



Discussion Questions:

What affects the moment of inertia of an object? (Mass distribution, distance from the axis of rotation.)

How does the placement of the force affect the rotational velocity? Why?

Things to Remember:

- Use the clipboard in the lab room to report any problems on the equipments.
- The printer may not print the correct equations. Remind the students to write down the equations in the prediction and fitting steps before they proceed to the next step.

Things your students should know by the end of this lab:

- 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.

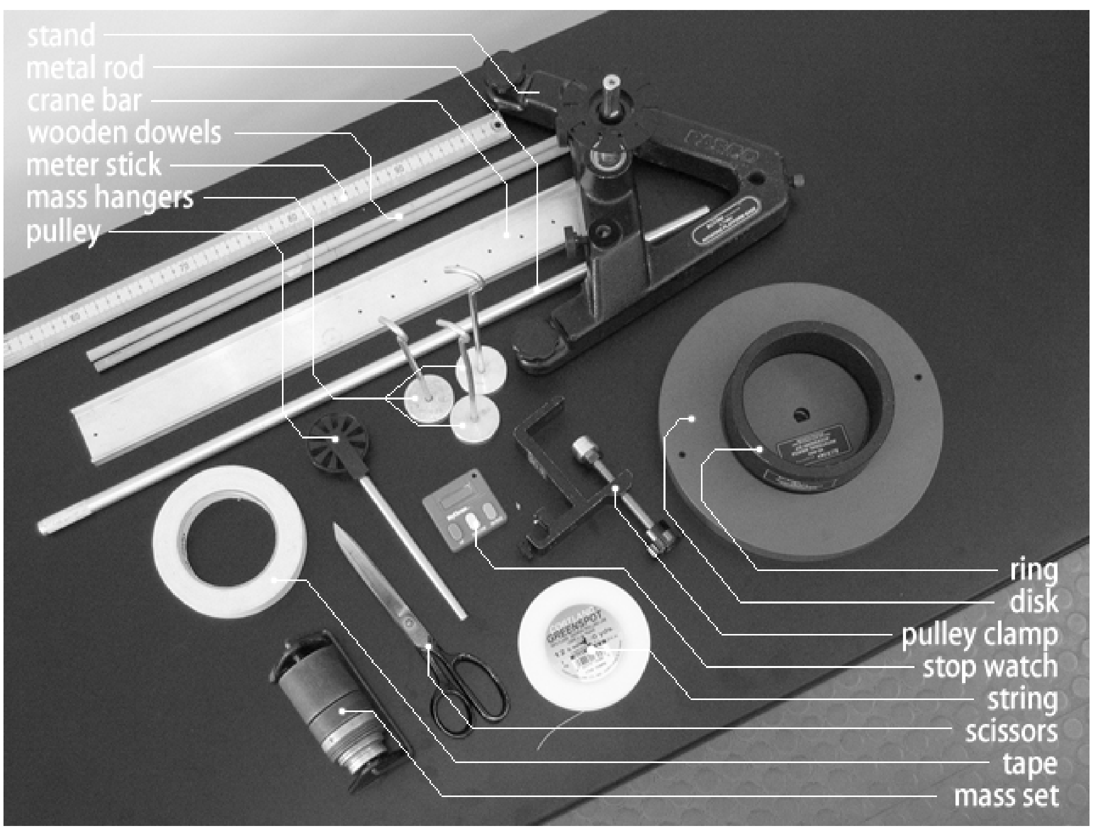
- Use the conservation principles of energy, momentum, and angular momentum for rigid body motion.

Things to check out before 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 setting the ring on the spinning disk for Problem #5. Conservation of momentum is always fun to play with.

NOTE: 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, however, if they are careful.

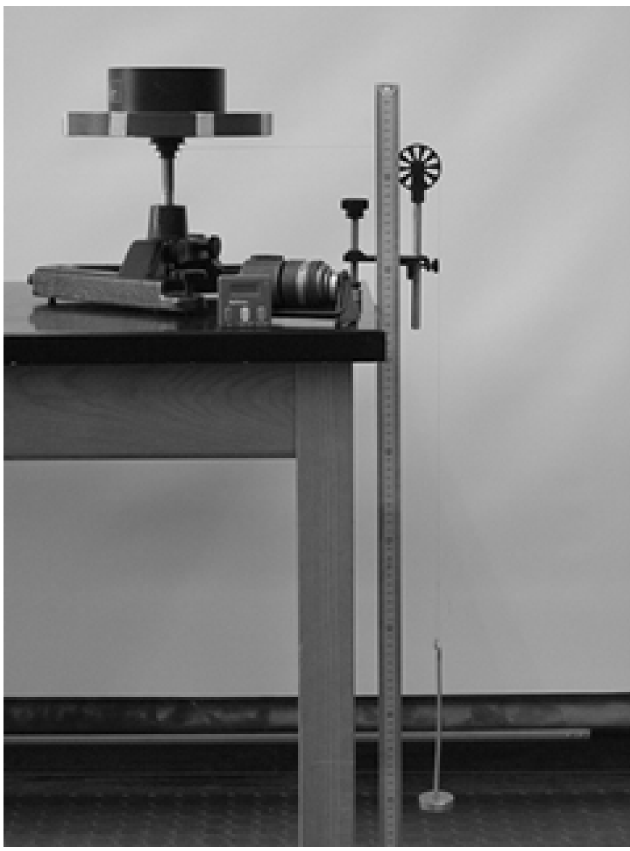
Equipment List:



Problem #1: Moment of Inertia Of A Complex System
Problem #2: Moment of Inertia About Different Axes
Problem #3: Moment of Inertia With An Off-Axis Ring

Purpose:

- **Problem #1:** To show the students that the rotational inertia of a 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 an unequal distribution of mass affects the rotational inertia of the system.



Teaching Tips:

1. 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.

2. 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.

3. 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.

4. 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.

5. 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.

Prediction 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: $I_{TOT} = \tfrac{1}{2}M_D R_D^2 + \tfrac{1}{2}M_S R_S^2$.

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

Problem #3:

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

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.

Problem #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.

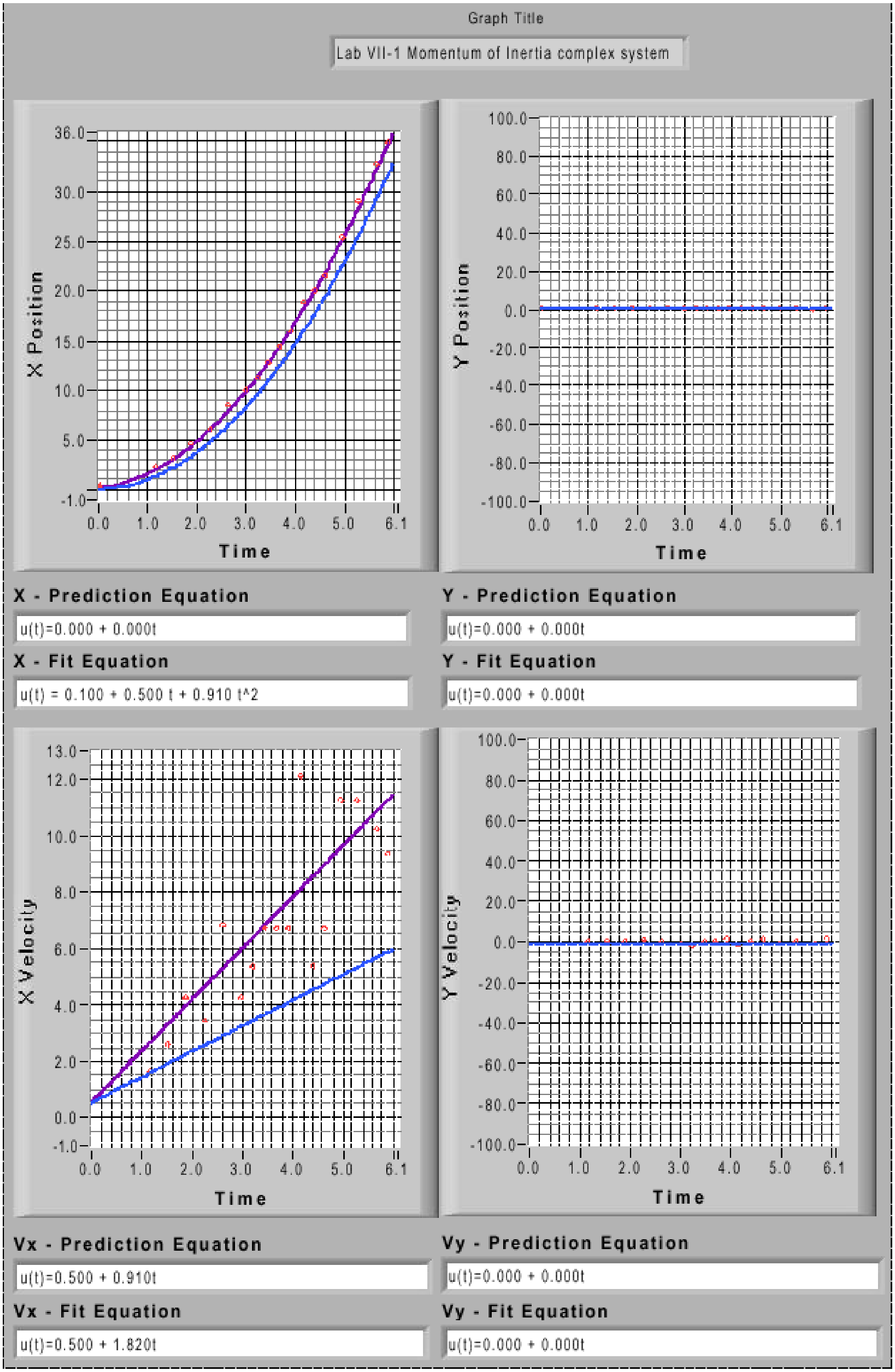
	Shaft	Disk	Ring	Spool
Mass (g)	222.5	1364.6	1431.1	-----
Radius (cm)	0.67	11.4	5.3/6.3	1.6

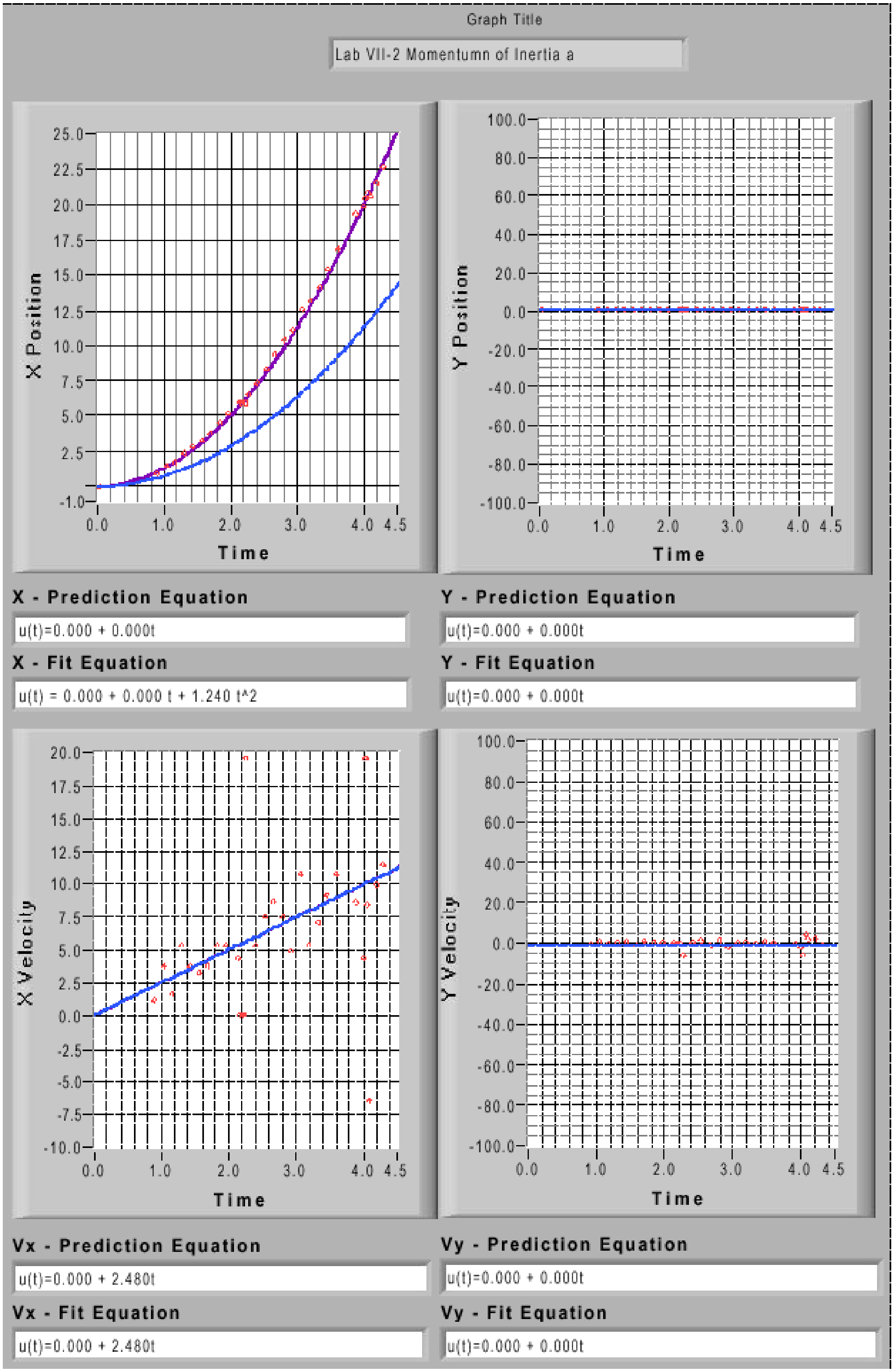
Problem #1
Measured acceleration: $a = 1.82$ (cm/s^2),
Mass of hanging object: $m = 100$ (g),
Momentum of Inertia from sum: I_{TOT}=1.372e-2(kg*m^2),
Momentum of Inertia from acceleration: I_{TOT}=1.376e-2(kg*m^2).

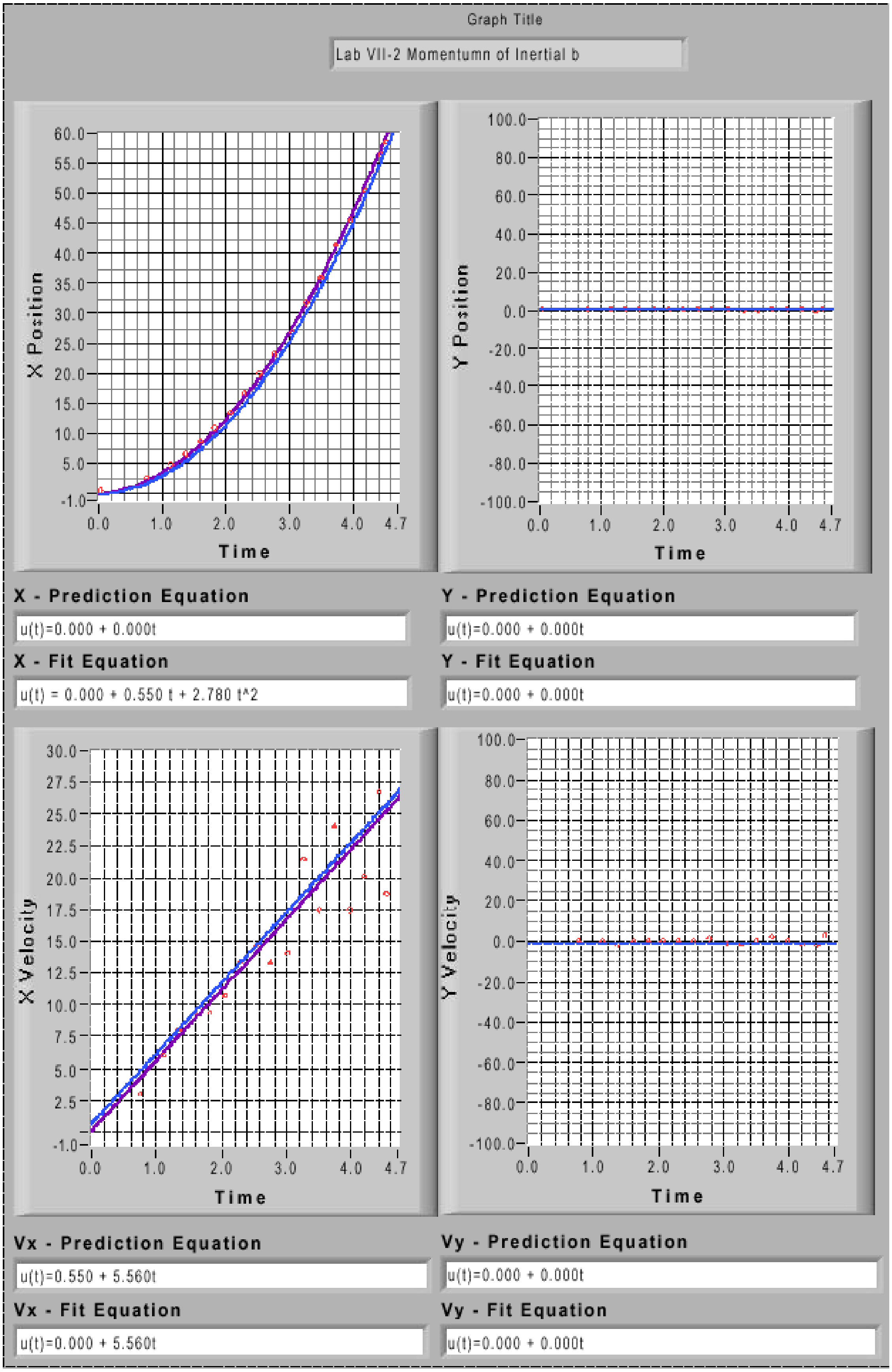
Problem #2
1) axis through center
Measured acceleration: $a = 2.48$ (cm/s^2),
Mass of hanging object: $m = 100$ (g),
Momentum of Inertia from sum: I_{TOT}=8.87e-3(kg*m^2),
Momentum of Inertia from acceleration: I_{TOT}=1.01e-2(kg*m^2).

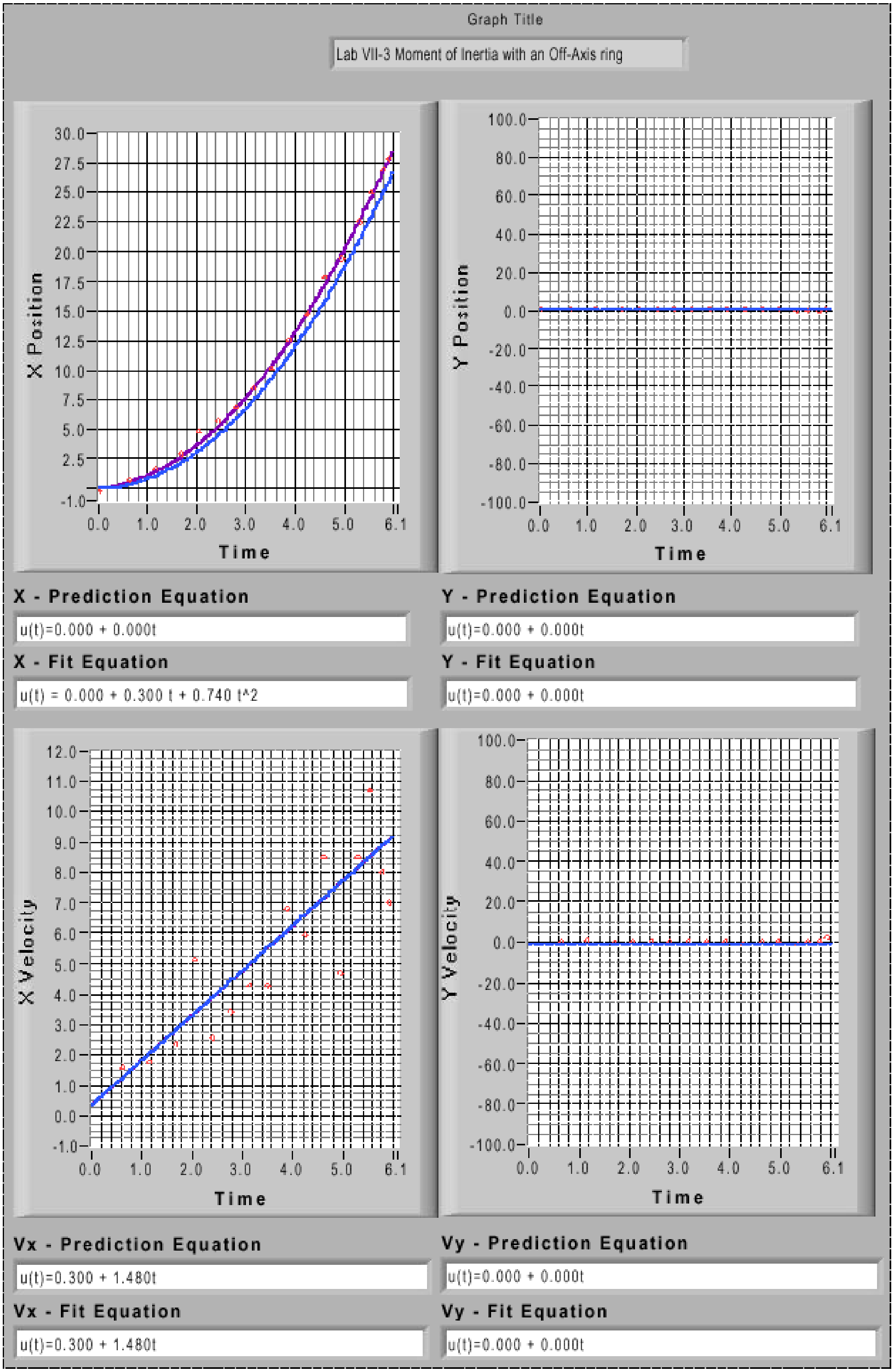
2) axis through diameter
Measured acceleration: $a = 5.56$ (cm/s^2),
Mass of hanging object: $m = 100$ (g),
Momentum of Inertia from sum: I_{TOT}=4.51e-3(kg*m^2),
Momentum of Inertia from acceleration: I_{TOT}=4.49e-3(kg*m^2).

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

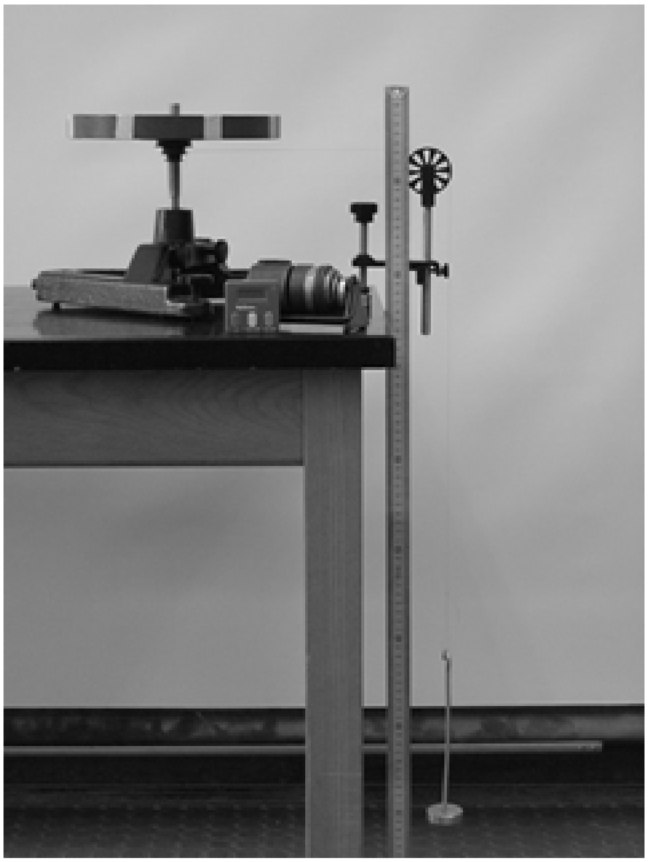

Graph Title
Lab VII-2 Momentumn of Inertial b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.000 + 0.550 t + 2.780 t^2
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.550 + 5.560t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t)=0.000 + 5.560t
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
X - Fit Equation
u(t) = 0.000 + 0.300 t + 0.740 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)=0.300 + 1.480t
Vx - Fit Equation
u(t)=0.300 + 1.480t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

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



Teaching Tips:

1 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.

2 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.

3 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: $$T = \frac{I}{I + mr^2} mg .$$

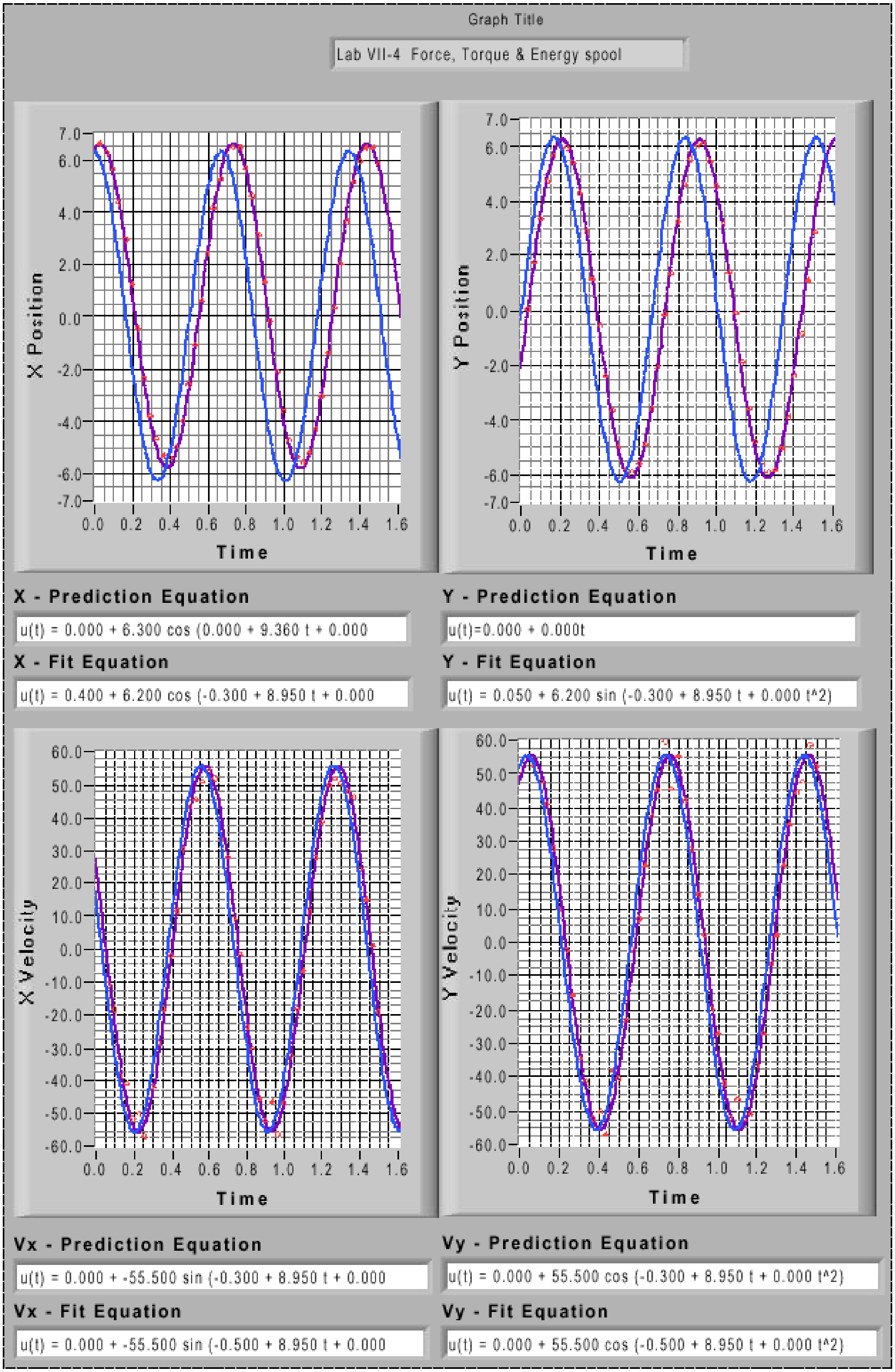
Sample Data:

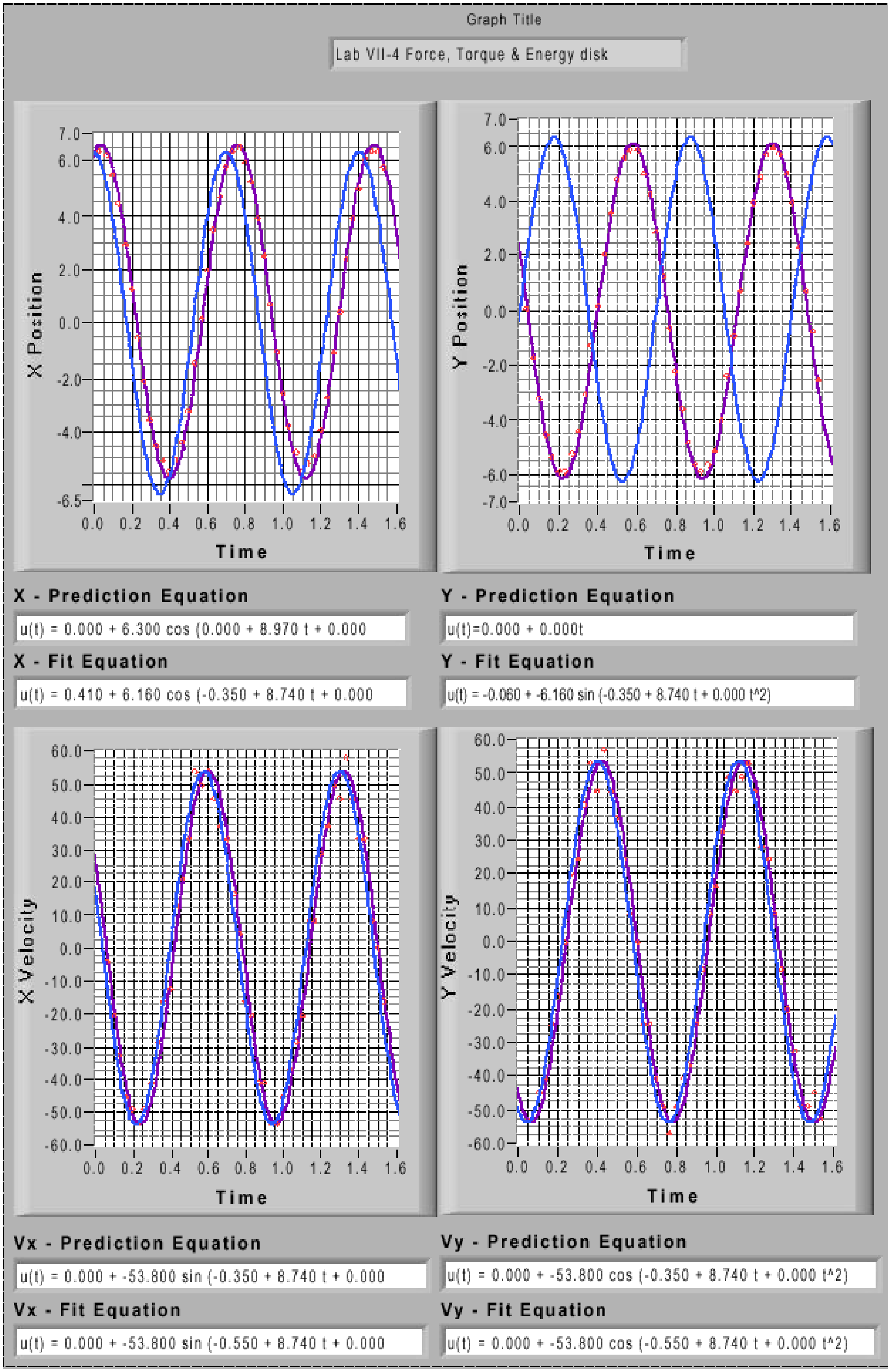
The printouts for the measurements of all final angular speeds are included at the end of following sample data.

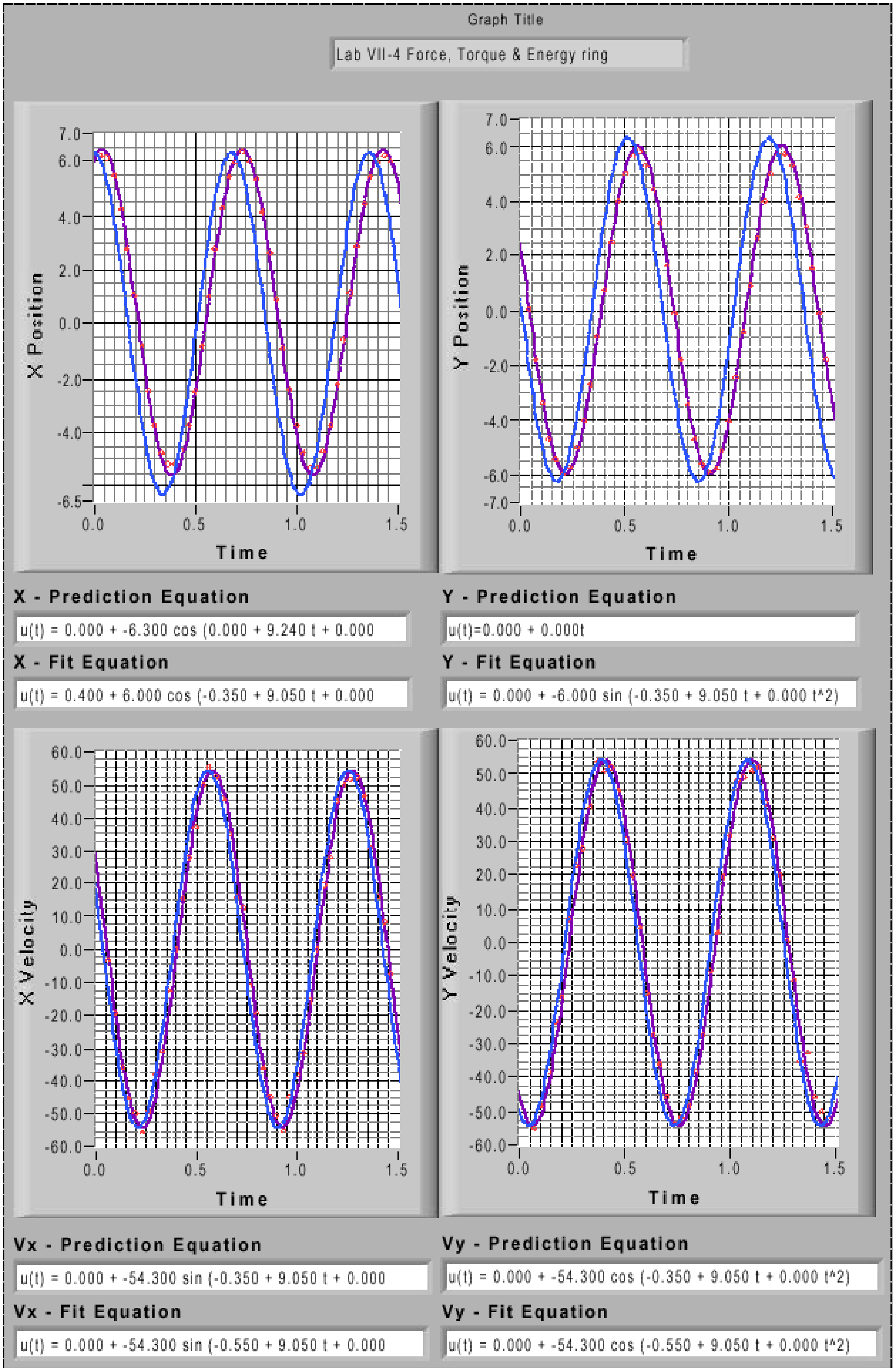
	Shaft	Disk	Ring	Spool
Mass (g)	222.5	1364.6	1431.1	-----
Radius (cm)	0.67	11.4	5.3/6.3	1.6

I=1.372e-2(kg*m^2),
$m = 100$ (g),
$h = 61.5$ (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

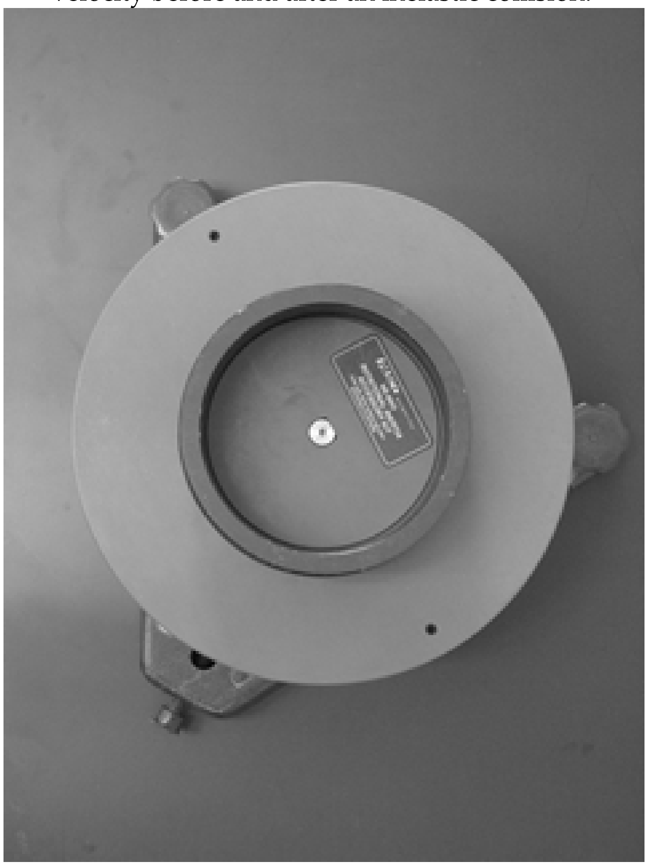

Graph Title
Lab VII-4 Force, Torque & Energy spool
X Position
Time
Y Position
X - Prediction Equation
u(t) = 0.000 + 6.300 cos (0.000 + 9.360 t + 0.000
X - Fit Equation
u(t) = 0.400 + 6.200 cos (-0.300 + 8.950 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t) = 0.050 + 6.200 sin (-0.300 + 8.950 t + 0.000 t^2)
X Velocity
Y Velocity
Vx - Prediction Equation
u(t) = 0.000 + -55.500 sin (-0.300 + 8.950 t + 0.000
Vx - Fit Equation
u(t) = 0.000 + -55.500 sin (-0.500 + 8.950 t + 0.000
Vy - Prediction Equation
u(t) = 0.000 + 55.500 cos (-0.300 + 8.950 t + 0.000 t^2)
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
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.400 + 6.000 cos (-0.350 + 9.050 t + 0.000
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
Vy - Prediction Equation
u(t) = 0.000 + -54.300 cos (-0.350 + 9.050 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -54.300 sin (-0.550 + 9.050 t + 0.000
Vy - Fit Equation
u(t) = 0.000 + -54.300 cos (-0.550 + 9.050 t + 0.000 t^2)

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.



Teaching Tips:
1. 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.
2. The timing error comes in twice; once to start the watch and again to stop it.
3. The disk should be rotating quickly enough so that the students can barely time it.
4. 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.
5. The students should drop the ring **GENTLY**.
6. Have the students perform multiple runs.

Discussion Questions:
What other ways can one change the angular velocity based on the conservation of angular momentum?

A good starting point is the traditional figure skating problem: when his arms are brought closer to the body, the skater rotates faster.

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),

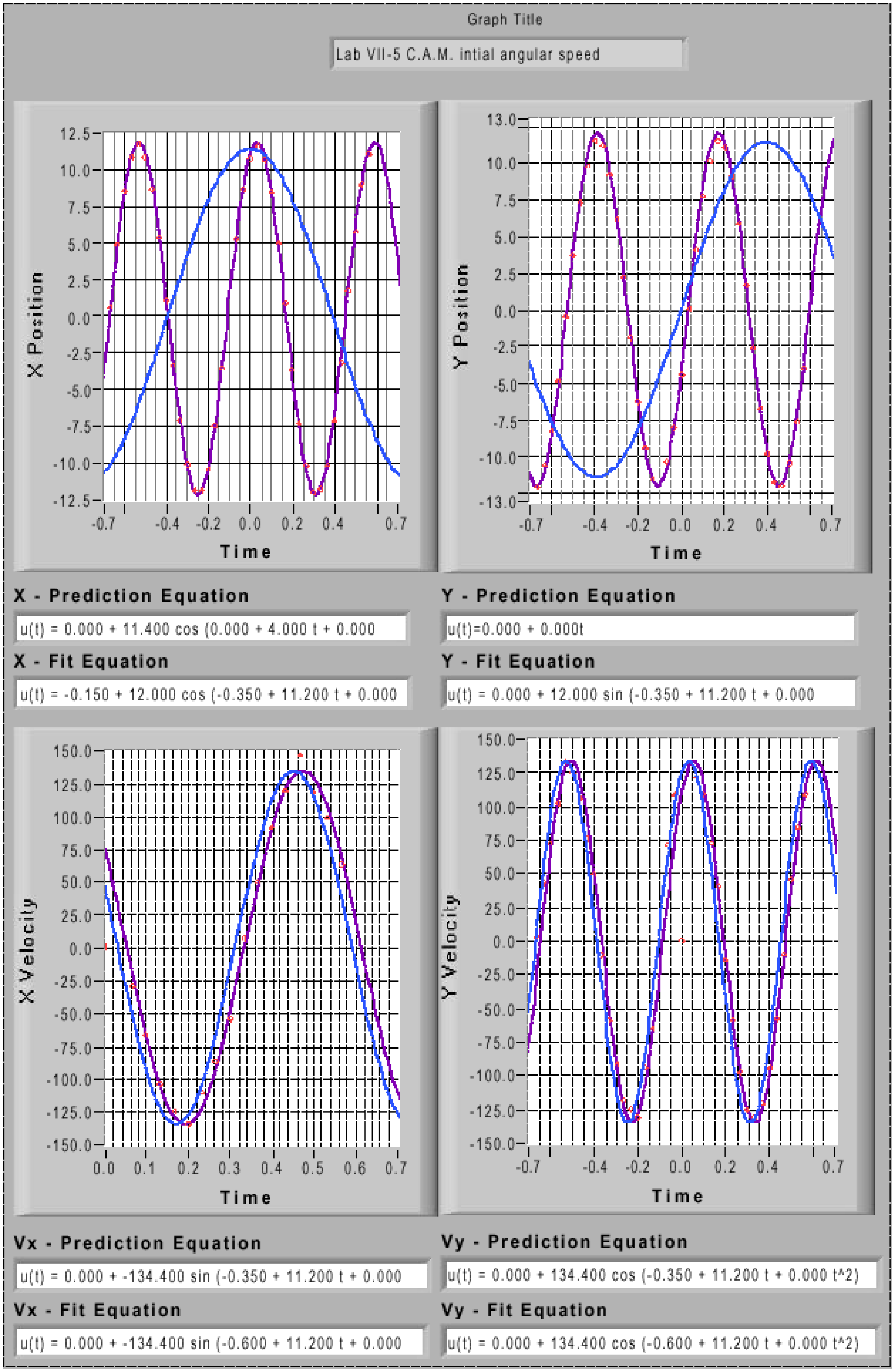
$I_{Ring} = 4.85$ e-3(kg*m^2),

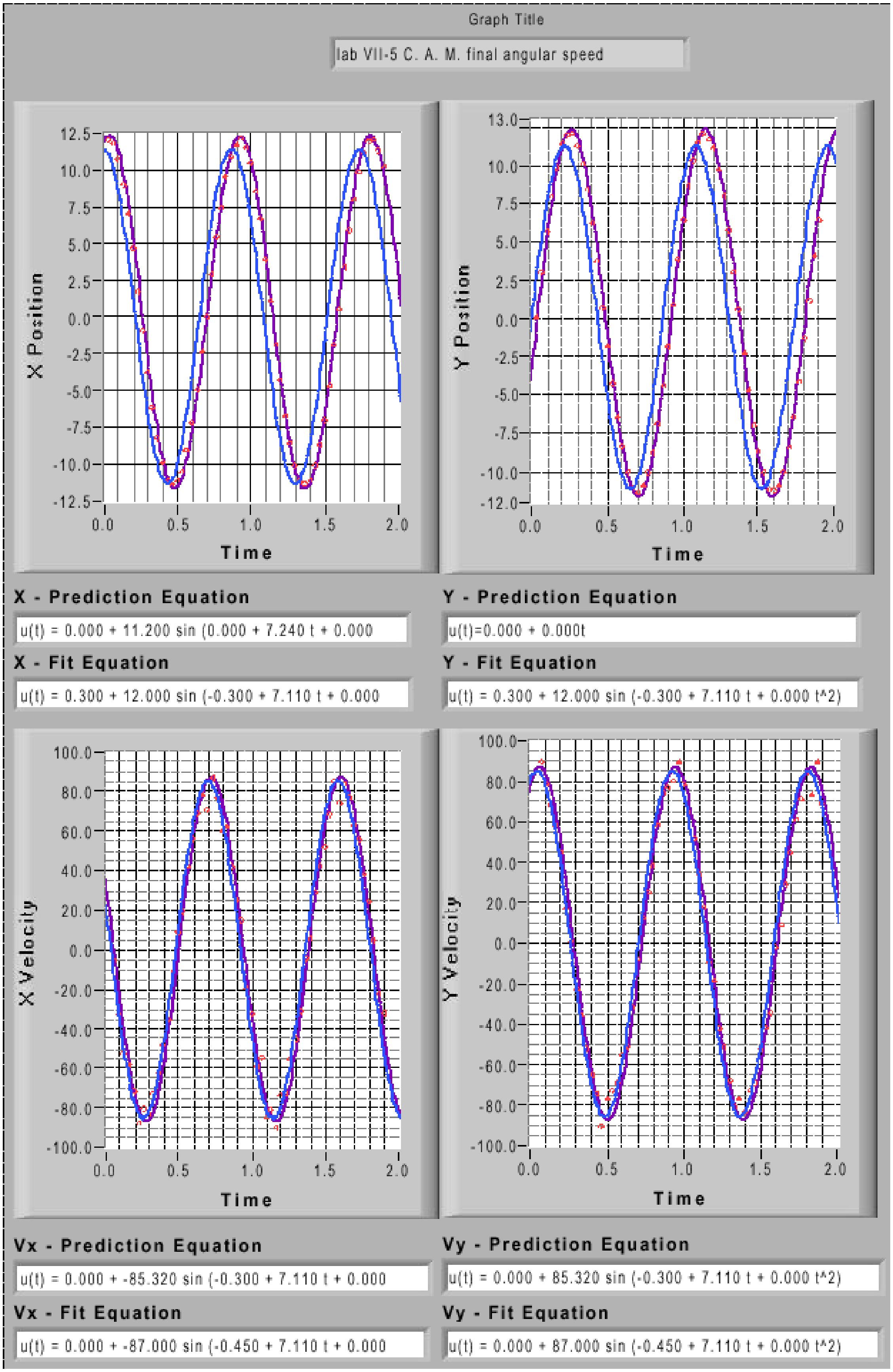
$I_{Shaft} = 4.994$ e-6(kg*m^2),

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

Predicted final angular speed ω_f =7.24(s^{-1}),

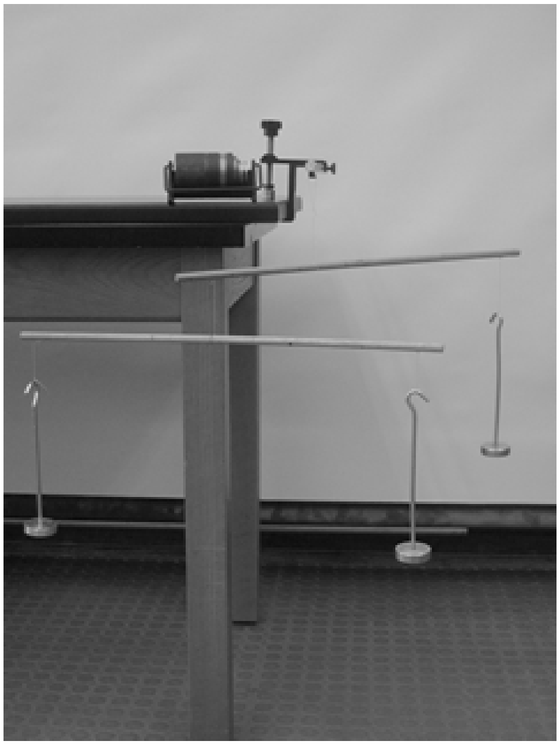
Measured final angular speed ω_f =7.11(s^{-1}).


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
Y - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.300 + 12.000 sin (-0.300 + 7.110 t + 0.000
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
Vy - Prediction Equation
u(t) = 0.000 + 85.320 sin (-0.300 + 7.110 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + -87.000 sin (-0.450 + 7.110 t + 0.000
Vy - Fit Equation
u(t) = 0.000 + 87.000 sin (-0.450 + 7.110 t + 0.000 t^2)

Problem #6: Designing a Mobile

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



Teaching Tips:
1. 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!

2. 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.

3. 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.

4. 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.

5. 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)

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.

Teaching Tips:

1. The rod has a uniform mass density, so it should be easy for the students to find the center of mass of the rod.
2. 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.
3. You will need to decide which masses to give to each group. Mix it up. Use masses in excess of 1 kg for the support line, and feel free to bundle some masses together. Also, give each group different values for the angle between the support line and the rod.
4. If the students mark the rod 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 steel rods because they are reusable in the next lab, and are easy to erase if marked with a pencil. However, the rods are slippery, so you will need to inform your students to wrap the parts of interest with tape. Make sure they take the tape off after they are done.

5. 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 bar; $d_A(d_B)$ 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 bar.

Sample Data:

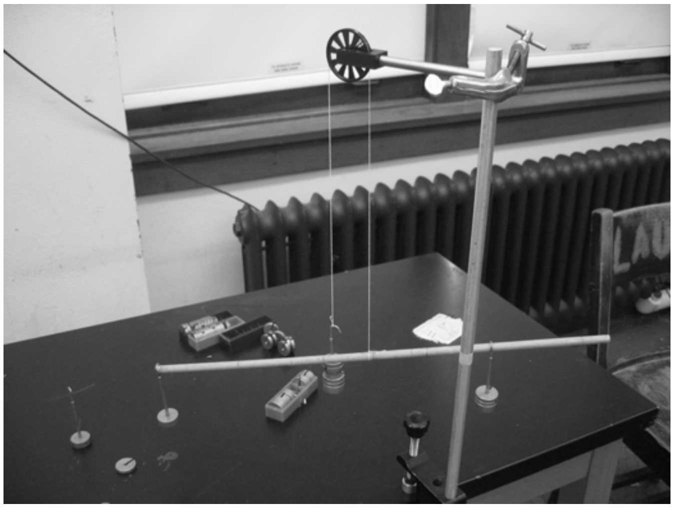
$d_A = 33.2$ (cm), $d_B = 23.6$ (cm), $d = 36.8$ (cm), $m = 160.6$ (g), $m_B = 196$ (g)

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

Problem #8: Translational and Rotational Equilibrium

Purpose:

- To present the importance of fulfilling BOTH translational and rotational equilibrium conditions in order to achieve static equilibrium.



Teaching Tips:

1. The rod has a uniform mass density, so it should be easy for the students to find the center of mass of the rod.
2. The equipment we have at the lab allows a minimum of 5g increment in mass. Get creative to get lower mass increments if you need to. You may use pieces of tape or strings.
3. If the students mark the rod 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 steel rods because they are reusable in the next lab, and are easy to erase if marked with a pencil. However, the rods are slippery, so you will need to inform your students to wrap the parts of interest with tape. Make sure they take the tape off after they are done.
4. For the sake of simplicity the bridge span is attached at the CM of the metal rod on which the counterweights are hanging.

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.

Varying the distance of one of the counterweights requires the masses to be changed. But since the total weight of the counterweights should be equal to the “bridge span”, no additional weight should be added one needs to redistribute the counterweights. Let the students figure this out for themselves.

Prediction and Warm up questions:

$$\frac{M_1}{M_2} r_1 = r_2 ,$$

where M_1 is the mass of the fixed counterweight at one end of the rod, M_2 is the mass of the counter weight with varying position on the rod, L is the length of the metal rod, and r_1 (r_2) is the distance between the center of the metal rod and the point at which counterweight 1(2) hangs.

Sample Data:

M_1 (g)	M_2 (g)	r_1 (cm)	r_2 (cm)	r_1 (cm)-calculated
95.0	95.0	27.6	27.6	27.6
85.0	105.0	27.6	22.4	27.7
75.0	115.0	27.6	17.9	27.4
70.0	120.0	27.6	15.7	26.9
50.0	140.0	27.6	9.6	26.9

TA Lab Evaluations

Physics 1301 Lab 7

Please return this sheet to Sean Albiston, to help us revise the labs

(circle one)

Instructors Pages:

Did you find the instructors pages useful? yes no

What other information would be useful to put in these pages?

Students:

Did the students find these exercises (circle one) useful fun boring other?

comments:

TA:

Given a choice would you teach these exercises again? yes no

Why or why not?

Results:

Did the students get good results for these exercises? yes no

Why or why not?

Room:

Was the room neat and clean when you entered the lab? yes no

When you left? yes no

Equipment:

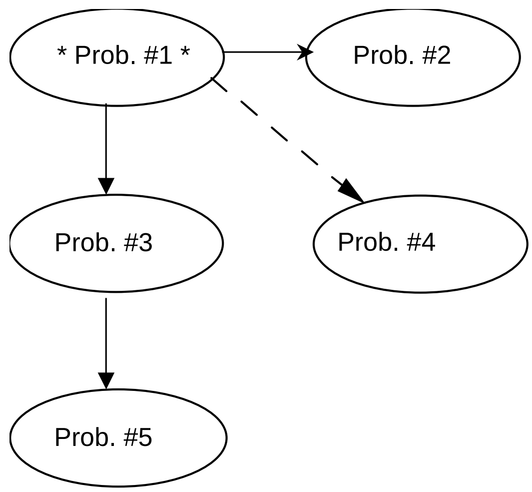
Was the lab equipment in working condition? yes no

What did not work? What was the problem? Were you able to fix it?

Laboratory VIII:
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. **Lab VIII problem 3 is done is the sample lab report in Appendix. Do not assign it for lab report !!!** Also Problem #5 must follow Problem #3 since it need some parameter (natural frequency) from Problem #3.



Discussion Questions:

What affects oscillation frequency of system? (Masses of cart and object, spring constant of springs.)

How does the additional force affect the amplitude of oscillation?

Things your students should know by the end of this lab:

- 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.

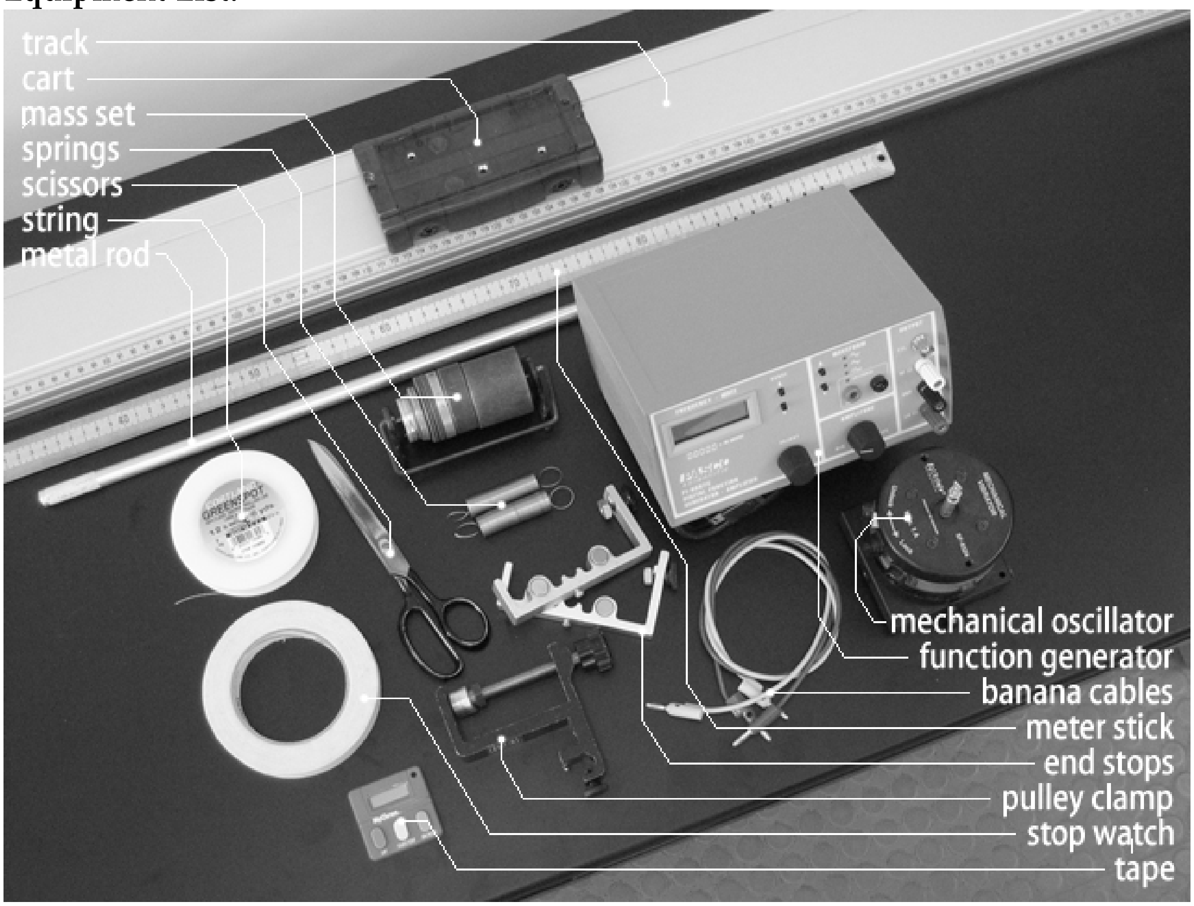
Things to check out before this lab:

- Check every wheel for every plastic cart to see if the wheel can last rotating at least two seconds by a gentle push.

- Use the soft springs.
- 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.

NOTE: The elastic limit of oscillation springs varies. Don't exceed individual spring limits during the experiment.

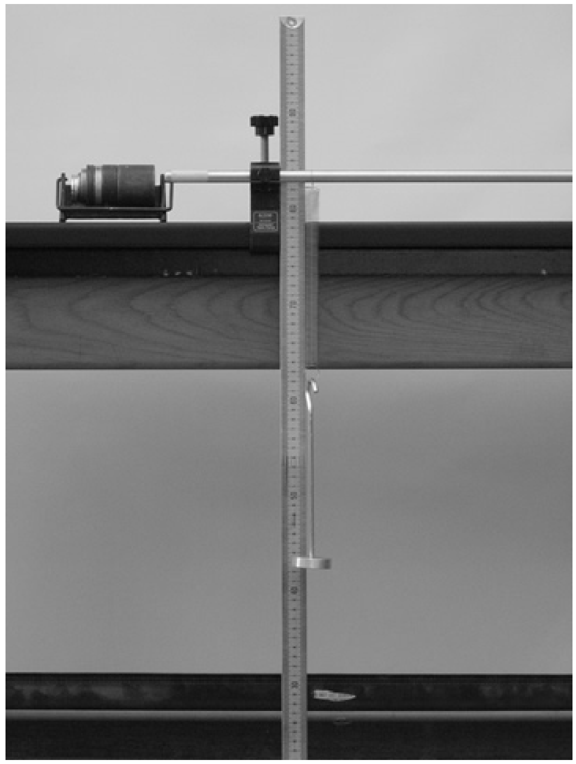
Equipment List:



Problem #1: Measuring Spring Constant

Purpose:

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



Teaching Tips:

1. Be sure not pass the elastic limit of springs. The hanging mass should be less than 200 g.
2. 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.
3. Choose the reference point at the mass holder not at the spring since the spring will stretch during oscillation.
4. 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.
5. 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

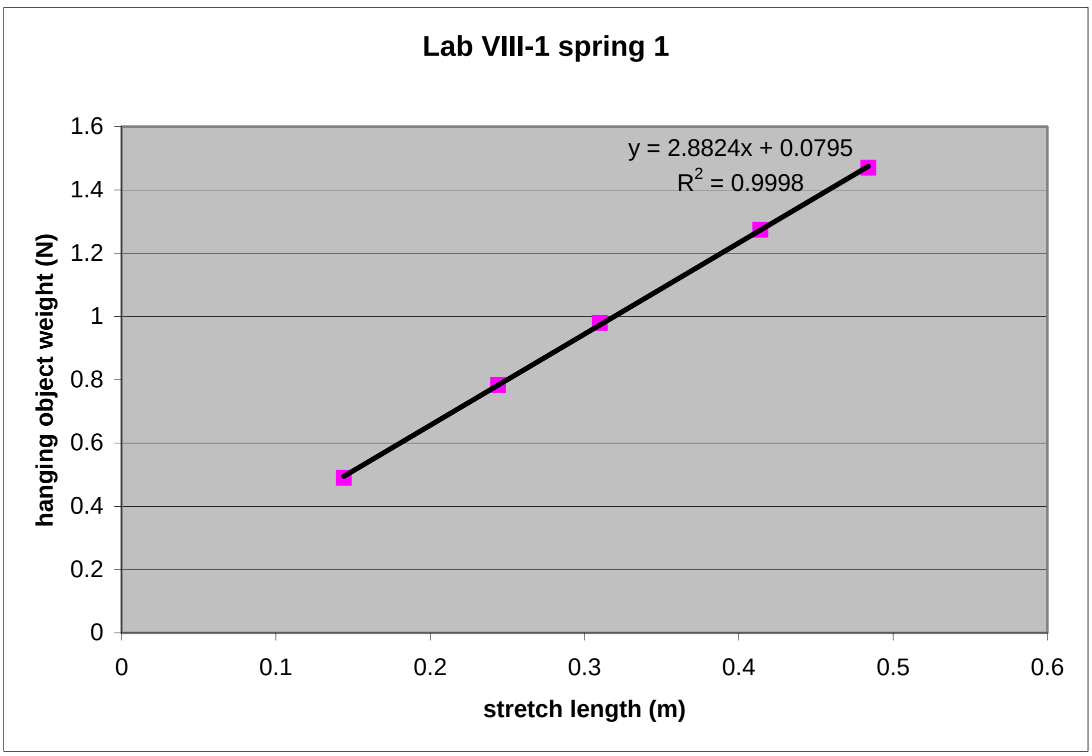
$$T = 2\pi\sqrt{\frac{m}{k}},$$

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):
1) Spring1

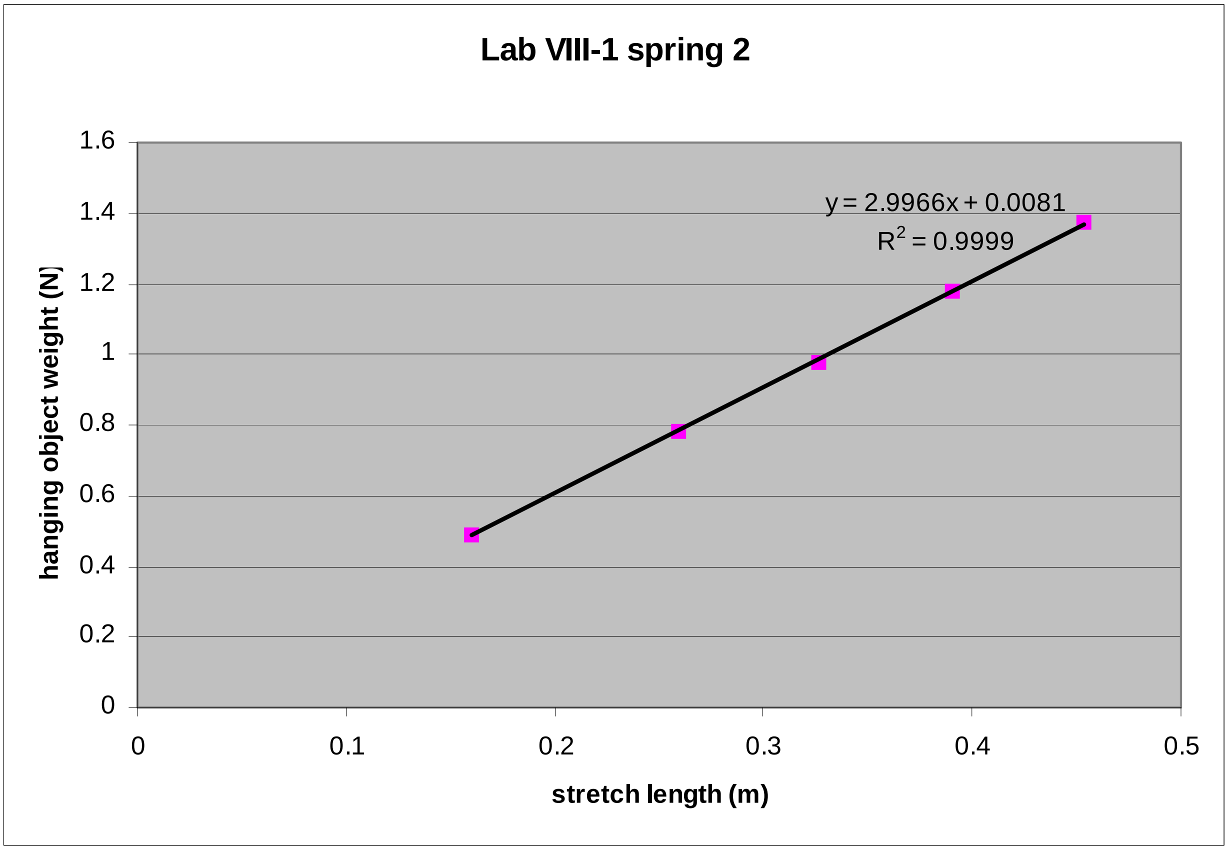
Stretch length d (cm)	14.4	24.4	31	41.4	48.4
Mass of object m (g)	50	80	100	130	150



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

2) Spring 2

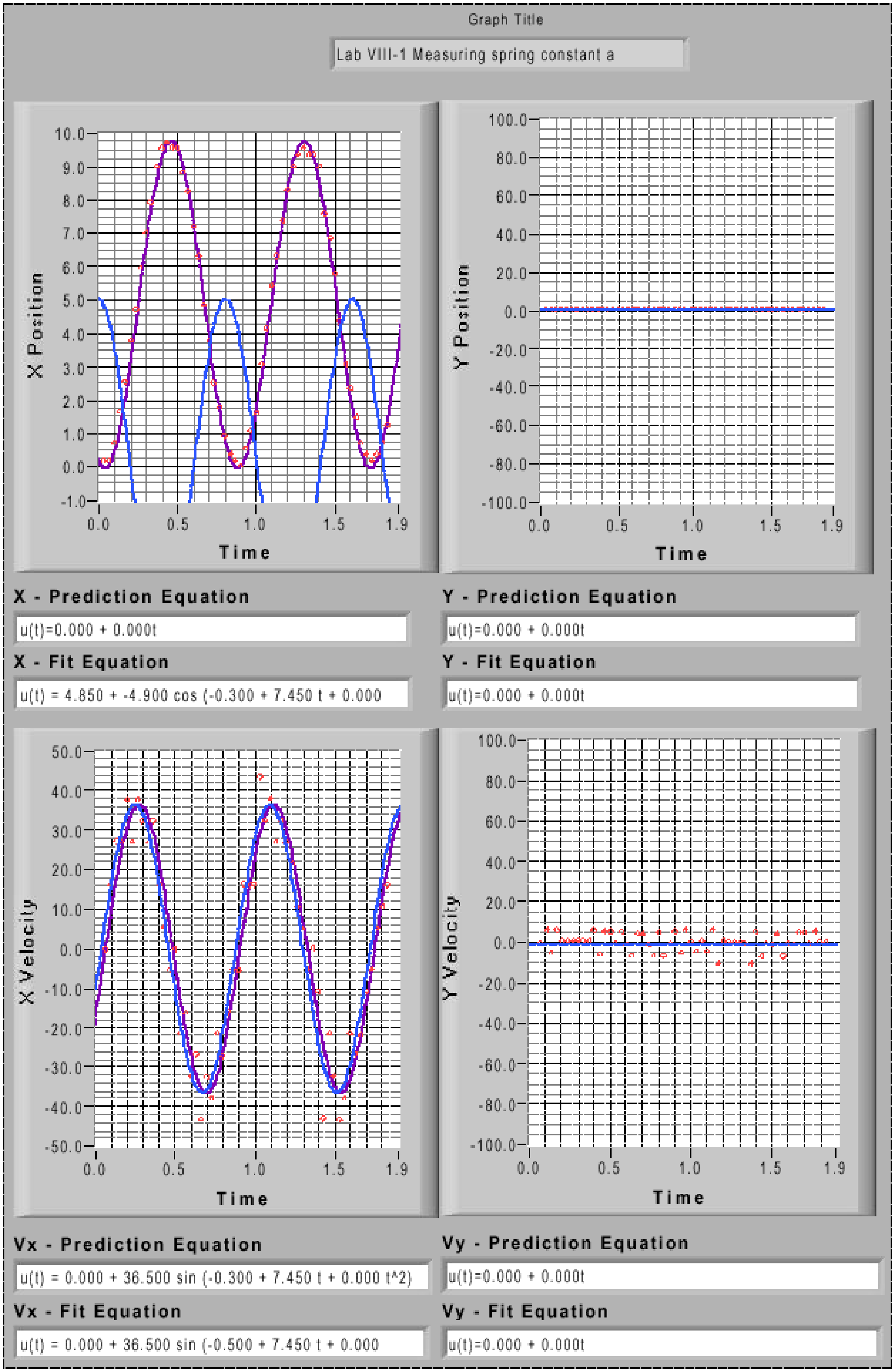
Stretch length d (cm)	16	25.9	32.6	39	45.4
Mass of object m (g)	50	80	100	120	140

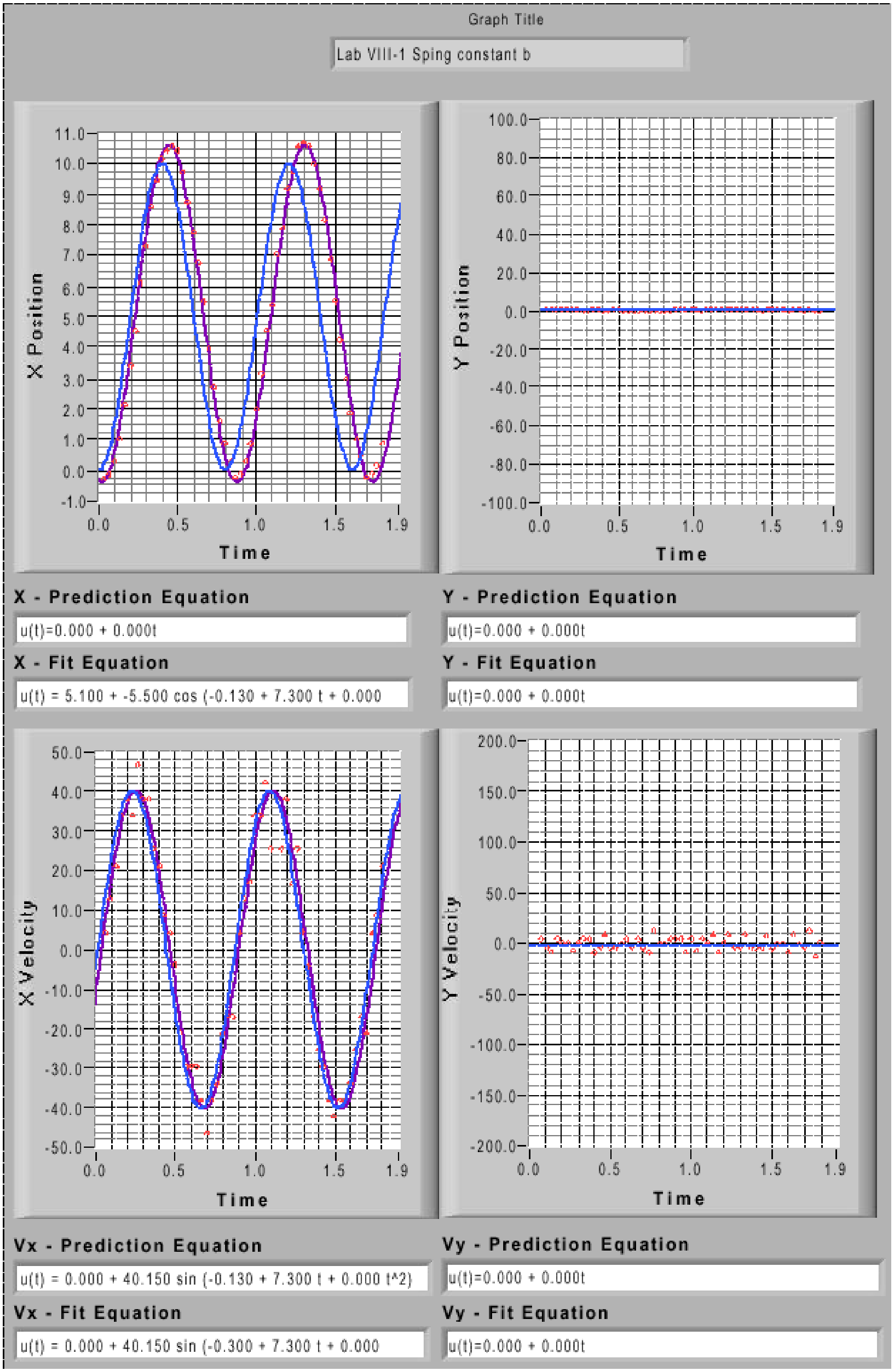


Spring constant $k_2 = 2.997$ (N/m).

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
X - Fit Equation
u(t) = 4.850 + -4.900 cos (-0.300 + 7.450 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 + 36.500 sin (-0.300 + 7.450 t + 0.000 t^2)
Vx - Fit Equation
u(t) = 0.000 + 36.500 sin (-0.500 + 7.450 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-1 Sping constant 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) = 5.100 + -5.500 cos (-0.130 + 7.300 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 + 40.150 sin (-0.130 + 7.300 t + 0.000 t^2)
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t) = 0.000 + 40.150 sin (-0.300 + 7.300 t + 0.000
Vy - Fit Equation
u(t)=0.000 + 0.000t

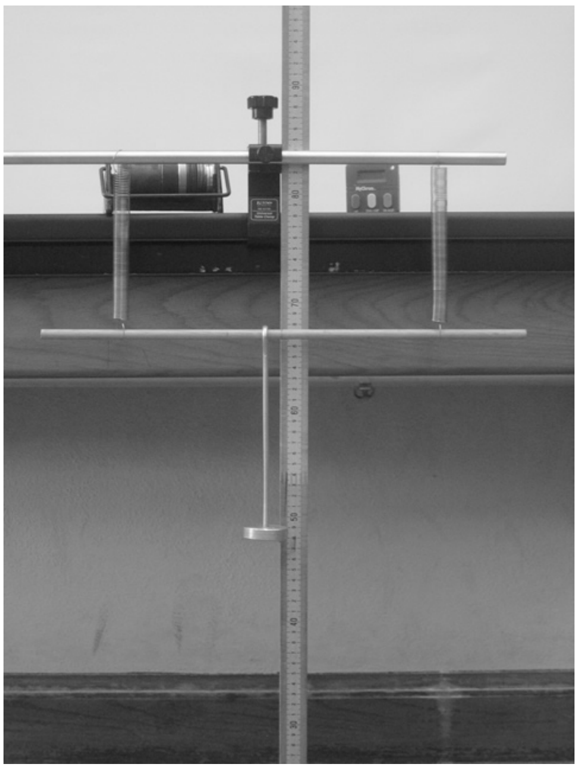
Problem #2: The Effective Spring Constant

Purpose:

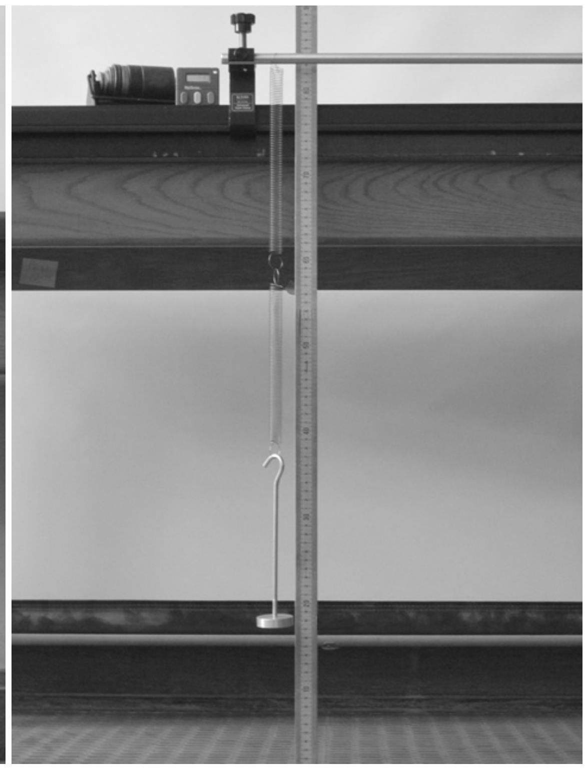
- To familiarize students with the properties of a spring furthermore and research the oscillation motion driven by different spring configurations.

Equipment Setup:

Part A



Part B



Teaching Tips:

1. Using method #2 of Problem #1 to measure the effective spring constants. Be sure not pass the elastic limit of springs.
2. Keep spring-object system moving vertically without wobbling. Especially avoid spring-object system shake frontward and backward.
3. For 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.
4. 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:

a) side_by_side configuration: $k^{/} = k_1 + k_2$,

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

b) end_to_end configuration: $k^{/} = \dfrac{k_1 k_2}{k_1 + k_2}$.

Derivation: Let $y = y_1 + y_2$, then Newton Second Law is $m\Delta\ddot{y} = \Delta F_2 = -k_2 \Delta y_2$

$\Rightarrow \Delta\ddot{y}_1 + \Delta\ddot{y}_2 = -\dfrac{k_2}{m}\Delta y_2$. Applying Newton Third Law, one gets $k_2 \Delta y_2 = k_1 \Delta y_1$. Then

$\dfrac{k_2}{k_1}\Delta\ddot{y}_2 + \Delta\ddot{y}_2 = -\dfrac{k_2}{m}\Delta y_2 \Rightarrow \Delta\ddot{y}_2 = -\dfrac{k_2 k_1}{m(k_2 + k_1)}\Delta y_2$. Finally, let's introduce effective spring constant $k^{/}$ equal to $\dfrac{k_1 k_2}{k_1 + k_2}$

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.

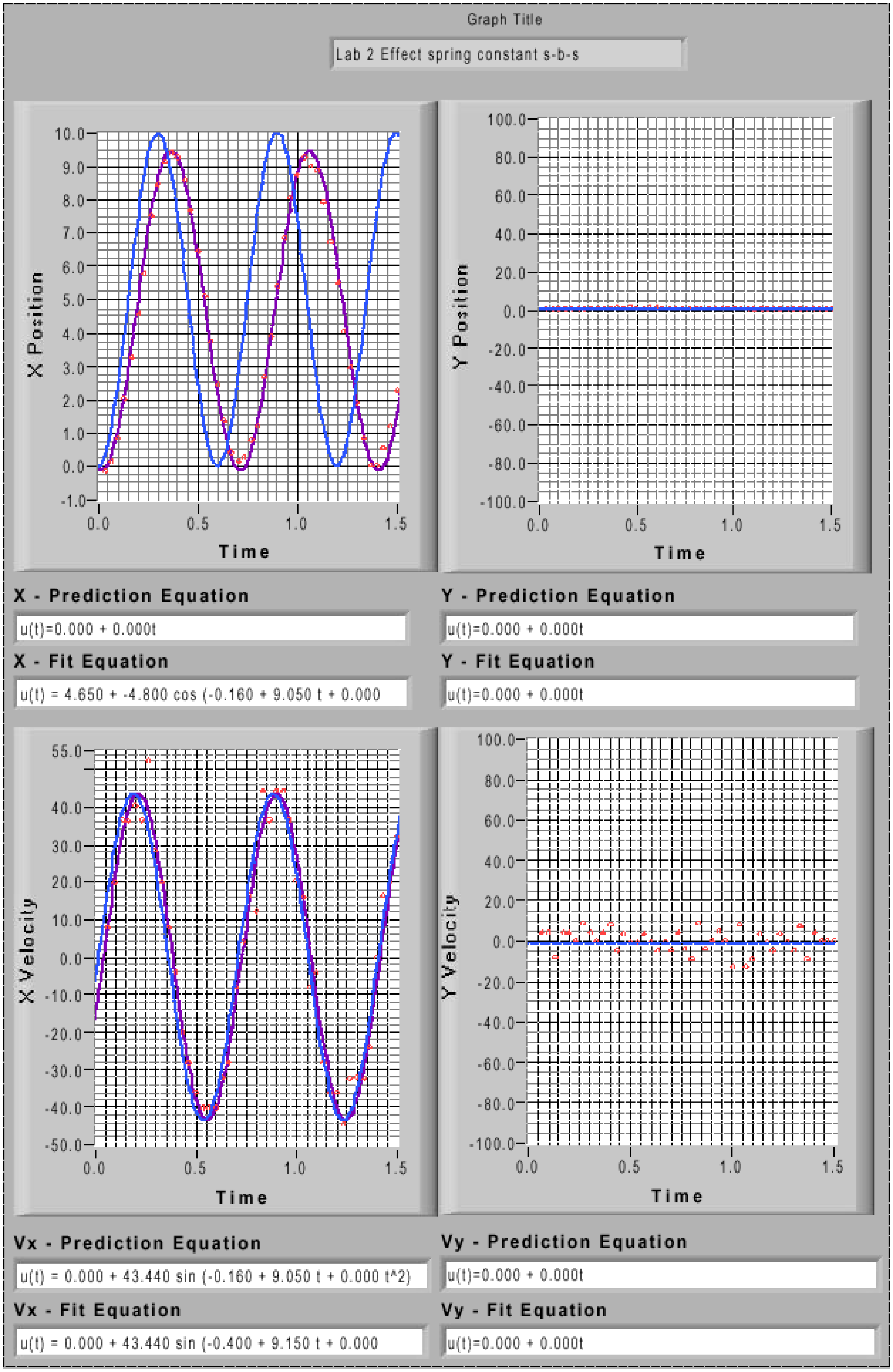
Sample Data:

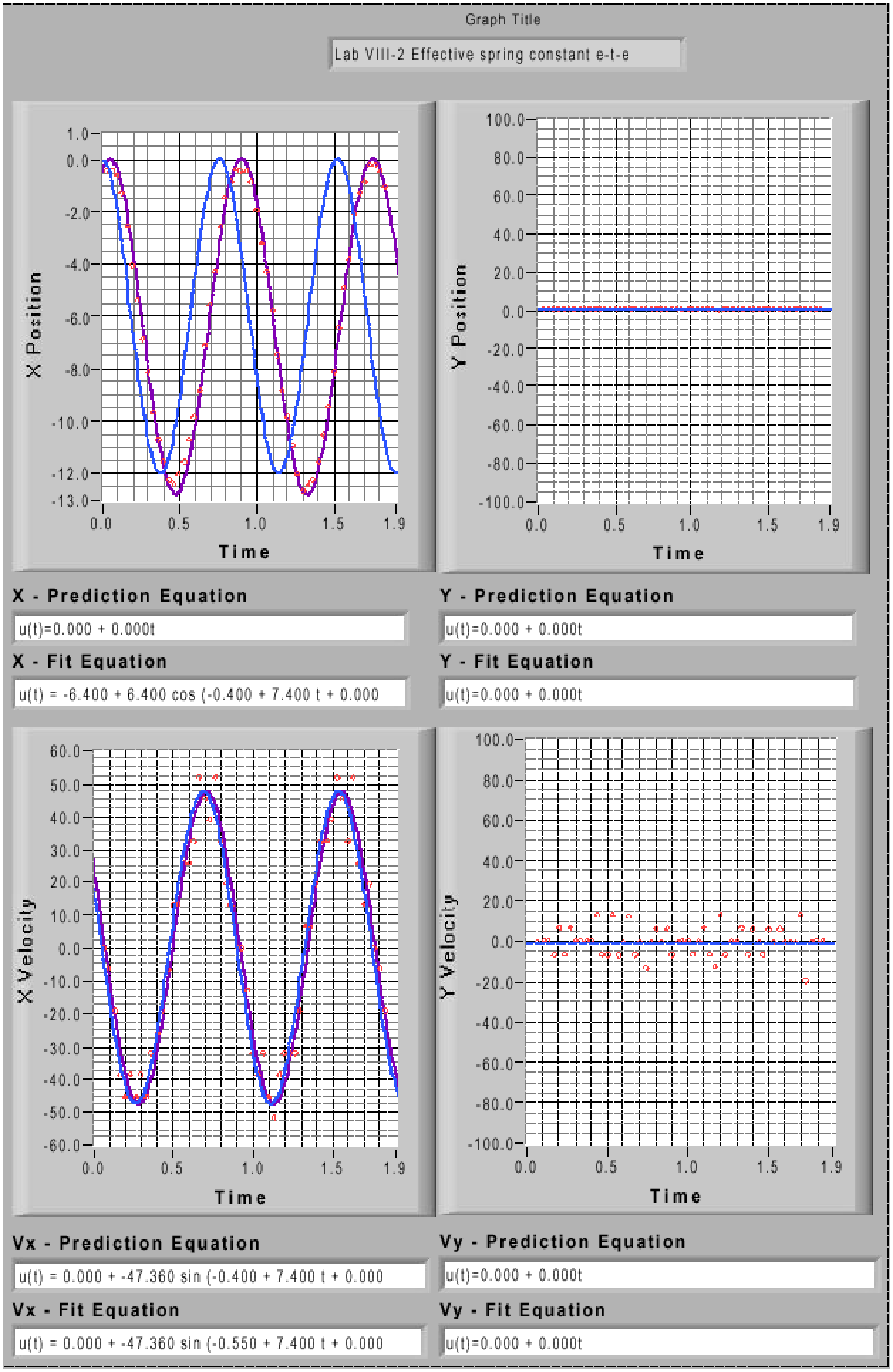
The printouts for the measurements of all oscillation periods are included at the end of following sample data.

$k_1 = 2.775$ (N/m), $k_2 = 2.665$ (N/m).

1) Side by side configuration
Mass of hanging object (including mass of the wooden rod): $m = 61$ (g),
Measured period: $T = 0.686$ (s),
Predicted effective spring constant: $k^{/} = k_1 + k_2 = 5.44$ (N/m),
Measured effective spring constant: $k^{/} = 5.11$ (N/m).

2) End to end configuration
Mass of hanging object: $m = 20$ (g),
Measured period: $T = 0.849$ (s),
Predicted effective spring constant: $k^{/} = k_1 k_2 /(k_1 + k_2) = 1.36$ (N/m),
Measured effective spring constant: $k^{/} = 1.10$ (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

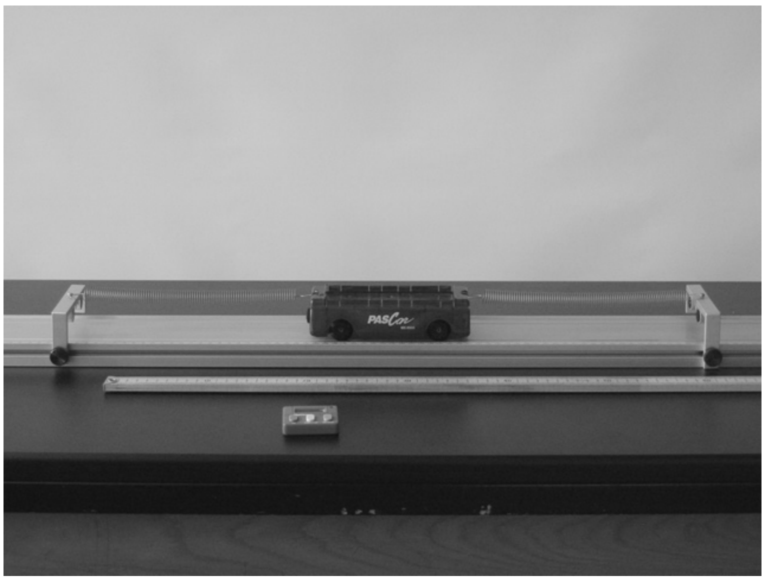

Graph Title
Lab VIII-2 Effective spring constant e-t-e
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = -6.400 + 6.400 cos (-0.400 + 7.400 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity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

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.

Lab VIII problem 3 is done in the sample lab report in Appendix. Do not assign it for lab report !!!



Teaching Tips:

1 Using strings to fix one top of the spring at the end stop and another top at one end of the cart.

2 Try a longer stretched distance to start oscillation but make sure not pass the elastic limit of the springs.

3 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.

4 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

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

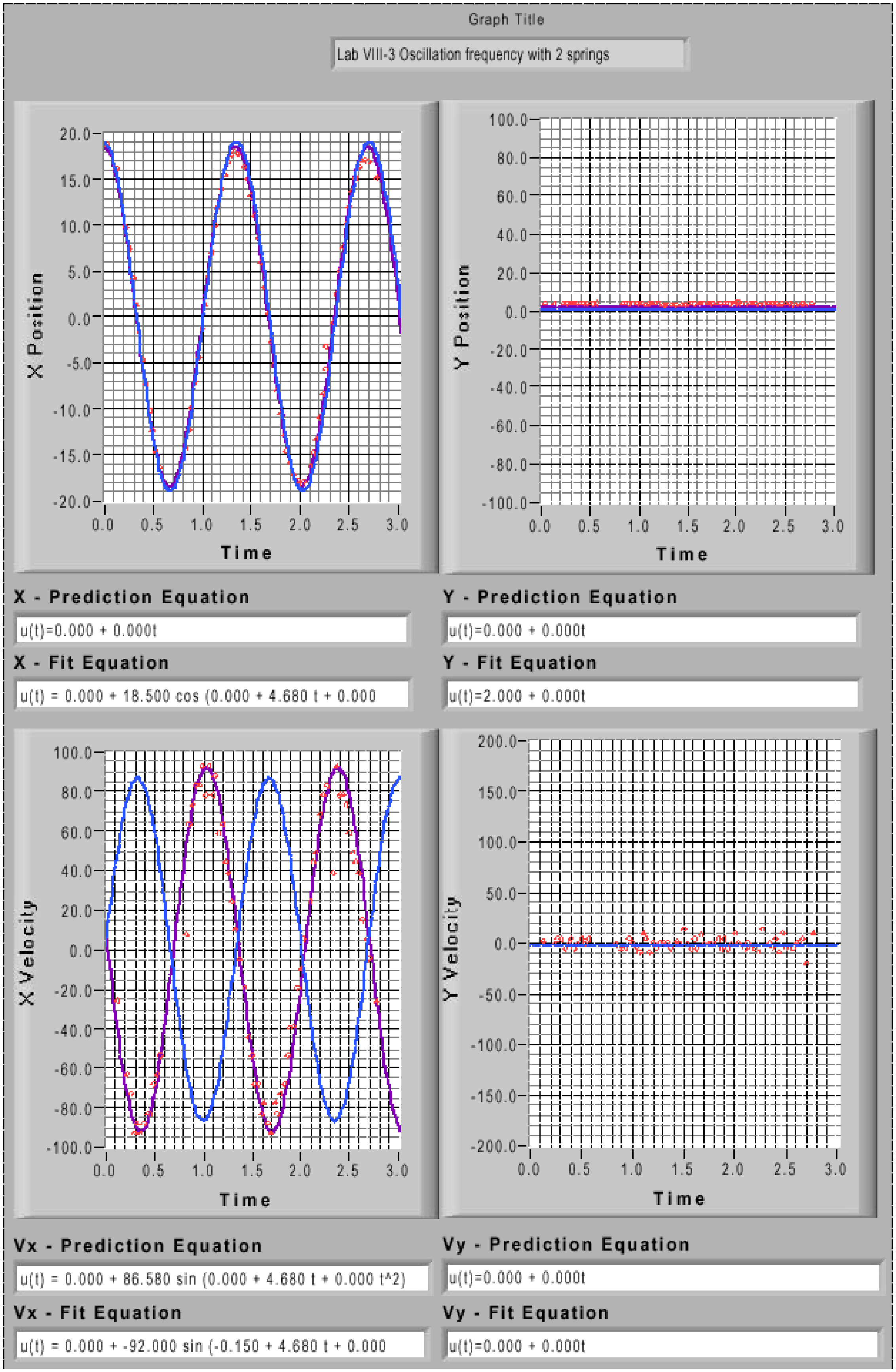
and so the frquency is

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

Sample Data:

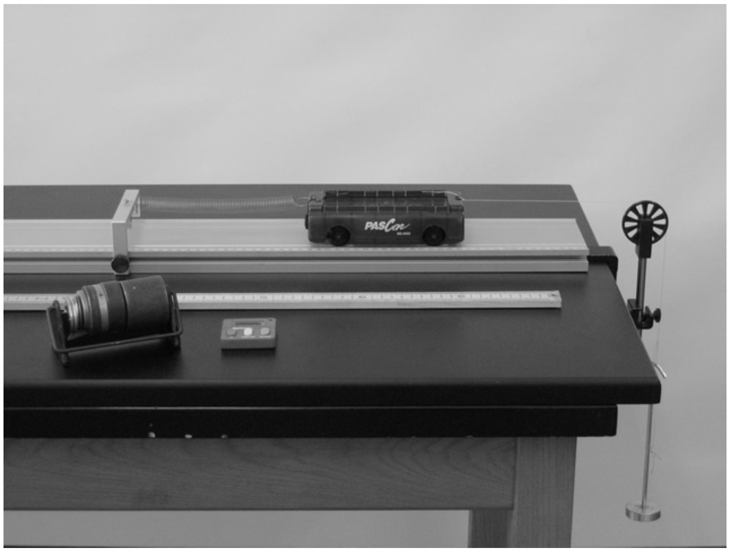
The printout for the measurement of oscillation frequency is included at the end of following sample data.

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
Y - 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 - 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)
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vx - Fit Equation
u(t) = 0.000 + -92.000 sin (-0.150 + 4.680 t + 0.000
Vy - Fit Equation
u(t)=0.000 + 0.000t

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.



Teaching Tips:

1. 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.

2. 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.
3. 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.
4. 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.

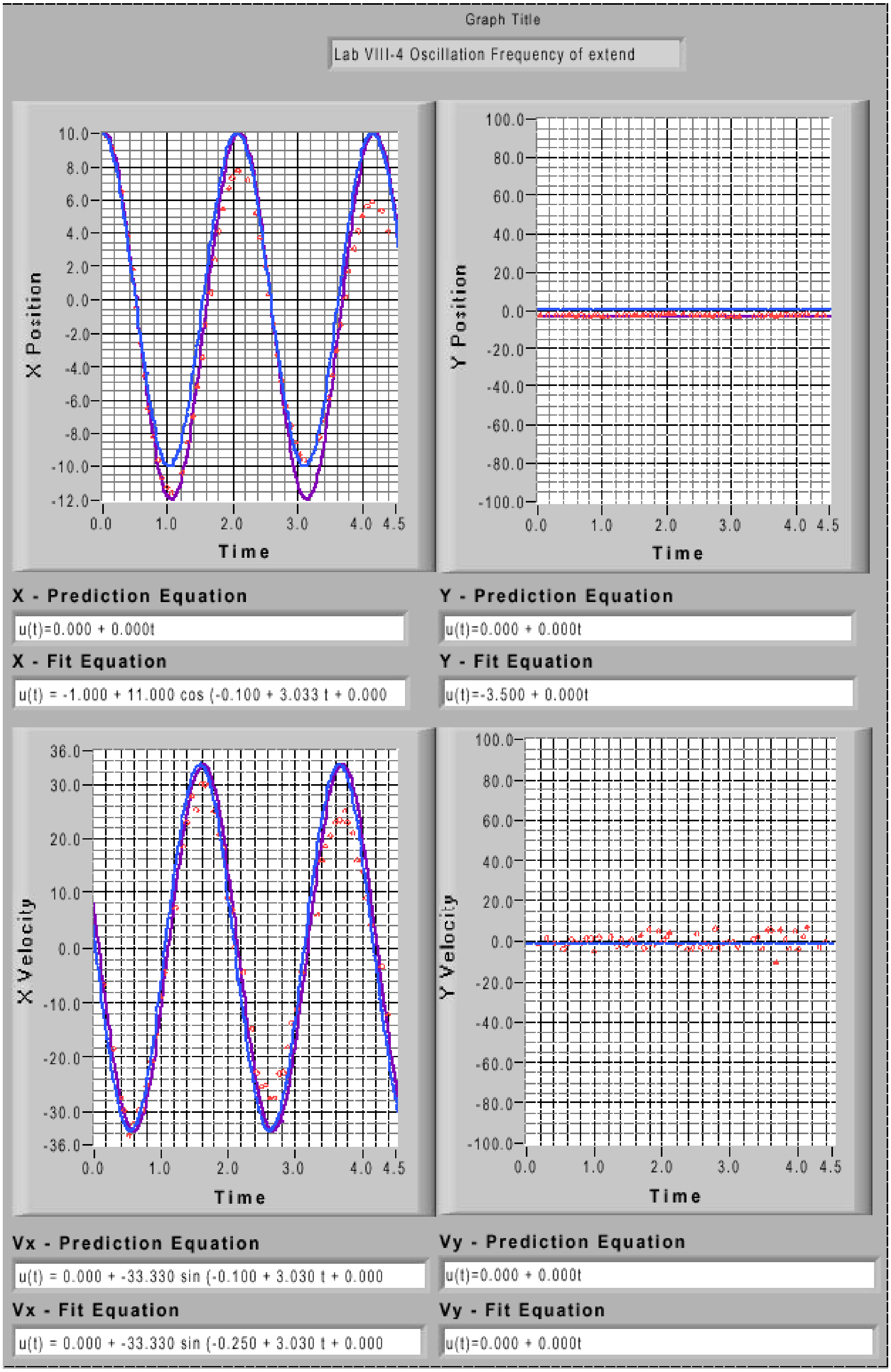
Prediction and Warm up questions:

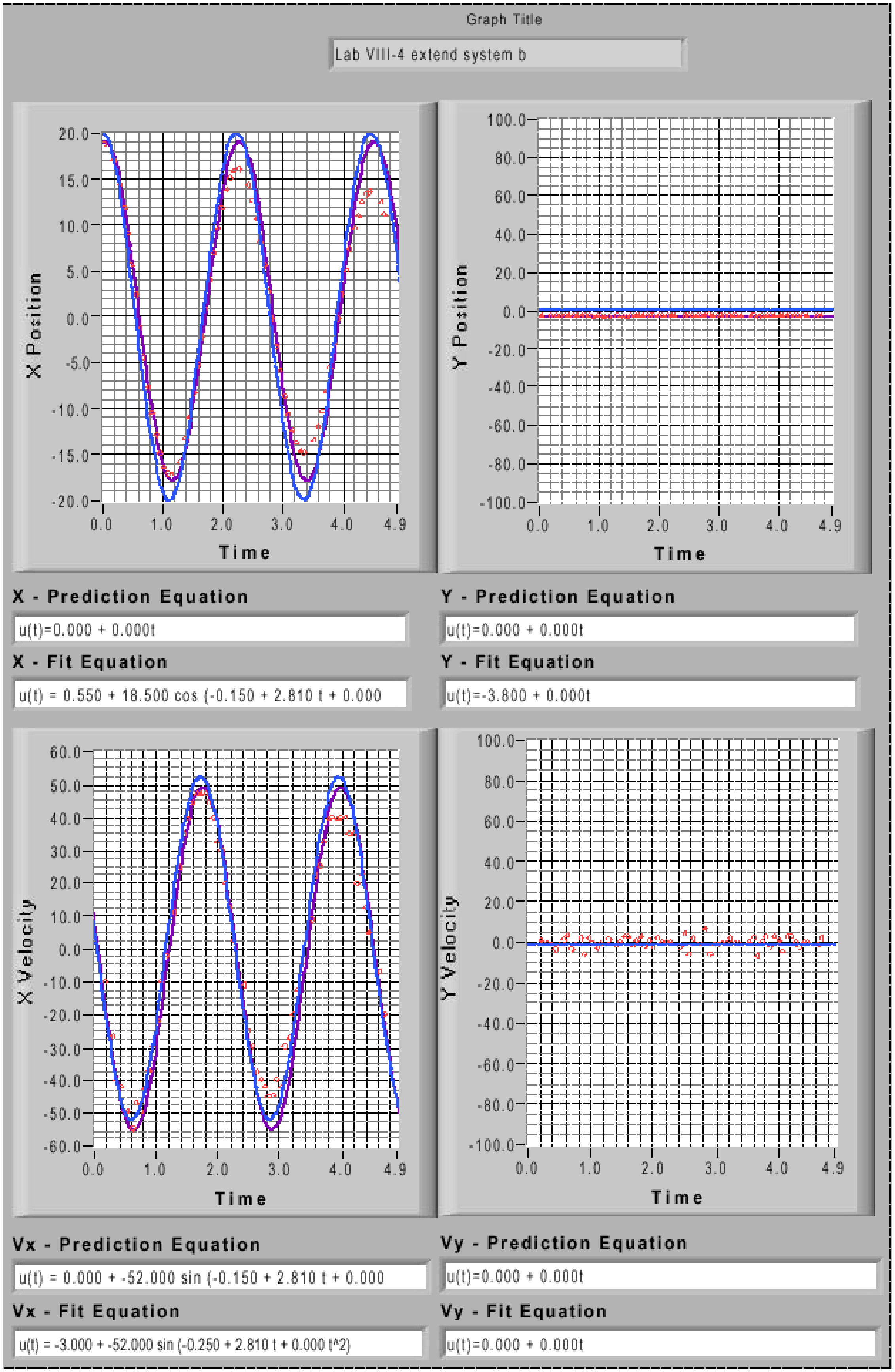
Oscillation frequency: $$f = \frac{1}{2\pi}\sqrt{\frac{k}{m+M}},$$

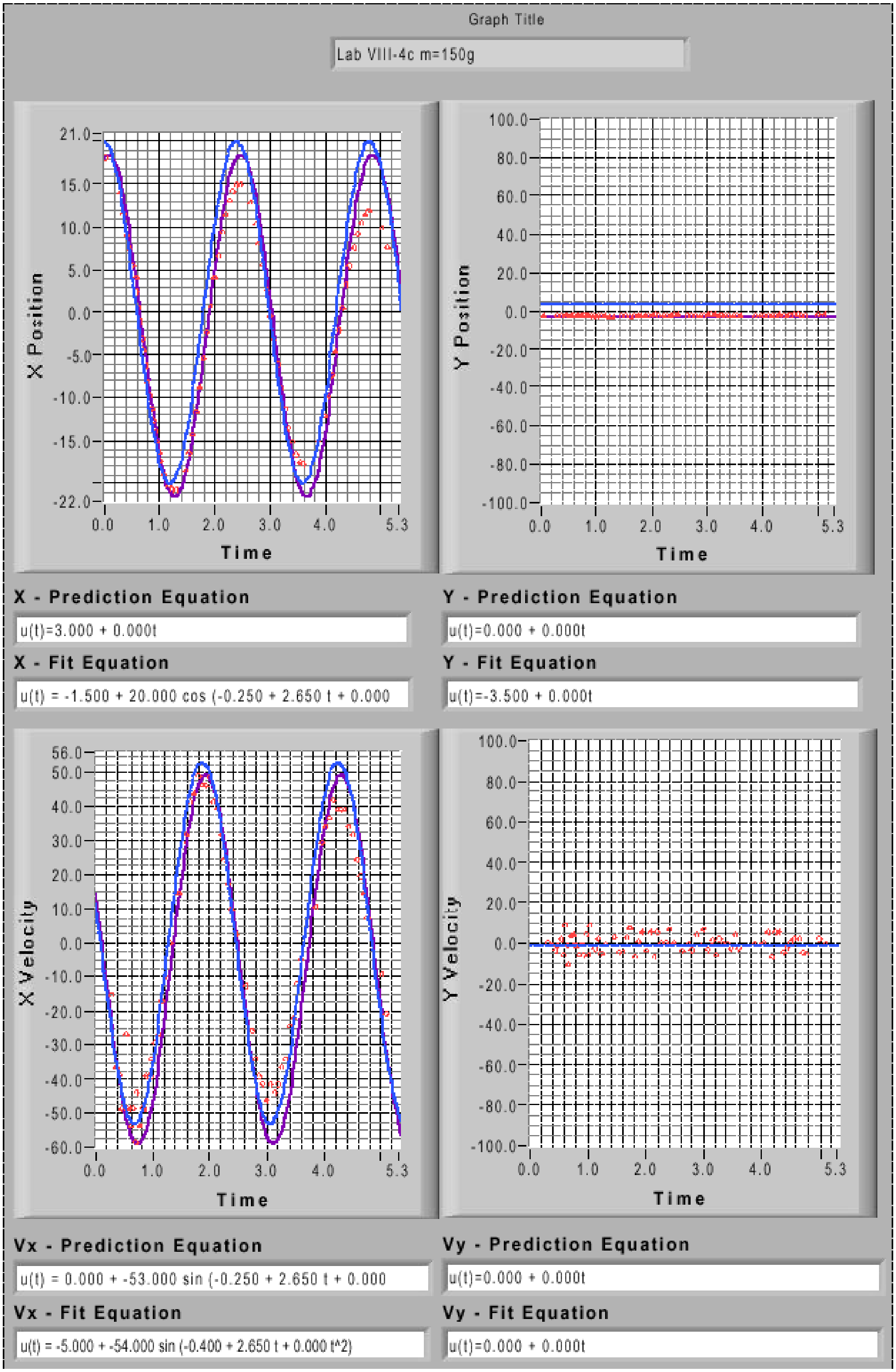
where m is the mass of the cart, k is the spring constant of an oscillation spring and M is the mass of the hanging object.

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

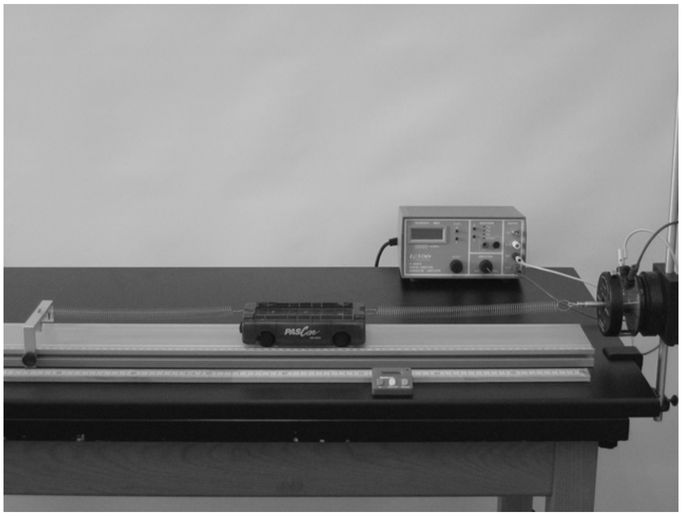

Graph Title
Lab VIII-4 extend system b
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = 0.550 + 18.500 cos (-0.150 + 2.810 t + 0.000
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-3.800 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - 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
X - Fit Equation
u(t) = -1.500 + 20.000 cos (-0.250 + 2.650 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 + -53.000 sin (-0.250 + 2.650 t + 0.000
Vx - Fit Equation
u(t) = -5.000 + -54.000 sin (-0.400 + 2.650 t + 0.000 t^2)
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

Problem #5: Driven Oscillations

Purpose:

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



Teaching Tips:

1. Take the result in Problem #3 as the natural frequency.
2. For low driving frequency, the cart may be bond by friction. You need to gently touch the cart to start it.
3. Near the natural frequency, choose 5 ~ 6 data points with an interval of 0.005 Hz.
4. 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.

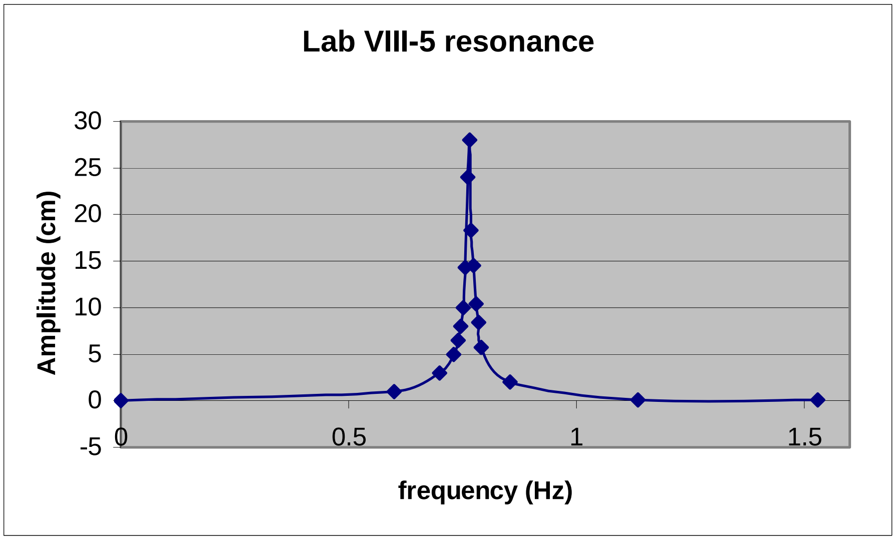
Prediction and Warm up questions:

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 8

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

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?

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? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

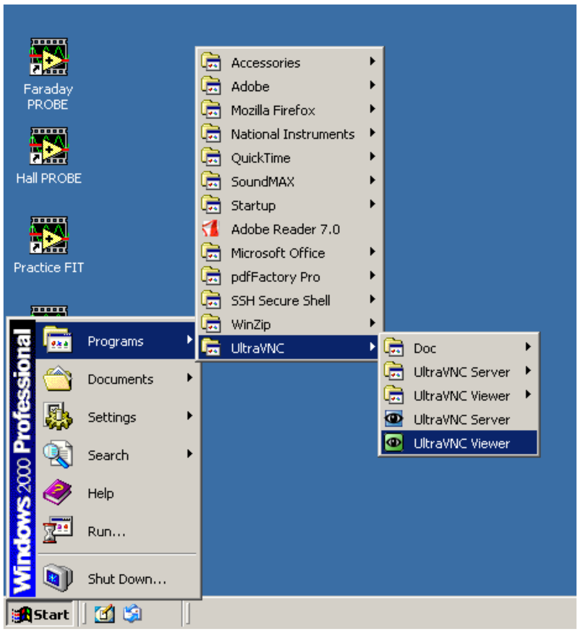
____

____

____

Reference Guide for Ultr@ VNC version 1.0.0

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 (most likely your physics department ID). If you would potentially like to broadcast a screen using the digital projector, log in to the instructor computer located near the printer. (Refer to the Digital Projector Reference for more information.) Access the program from the Start menu, Programs folder, UltraVNC, and UltraVNC Viewer. Refer to Figure 1.

You can also access the program from My Computer:
C:\Program Files\UltraVNC\UltraVNC Viewer

Fig. 1

The following pop-up window should appear, requesting the name of the display host:

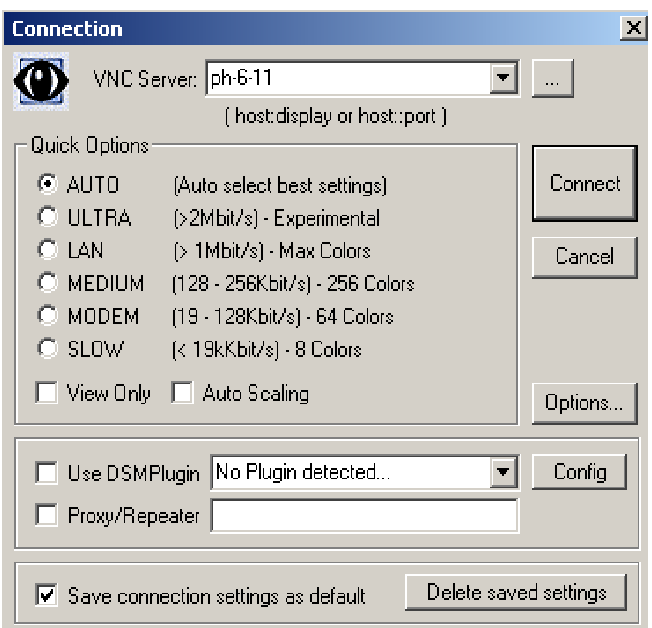


Fig. 2

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 ph-#-##.

If you want to change connection options, click the ***Options*** button. Another pop-up window will appear (Figure 3). *Auto select best settings* is the default. From this window you can change *Mouse Cursor* options and select *Display* options.

Click ***Connect*** to begin viewing the selected Desktop. An Authentication pop-up window will appear, requesting you to enter a username and password. Type in "vnc" and "labvnc". Click ***Log On***.

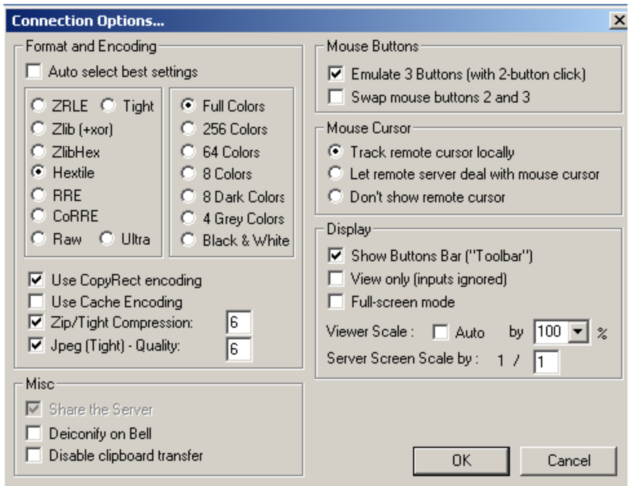


Fig. 3: Connection Options

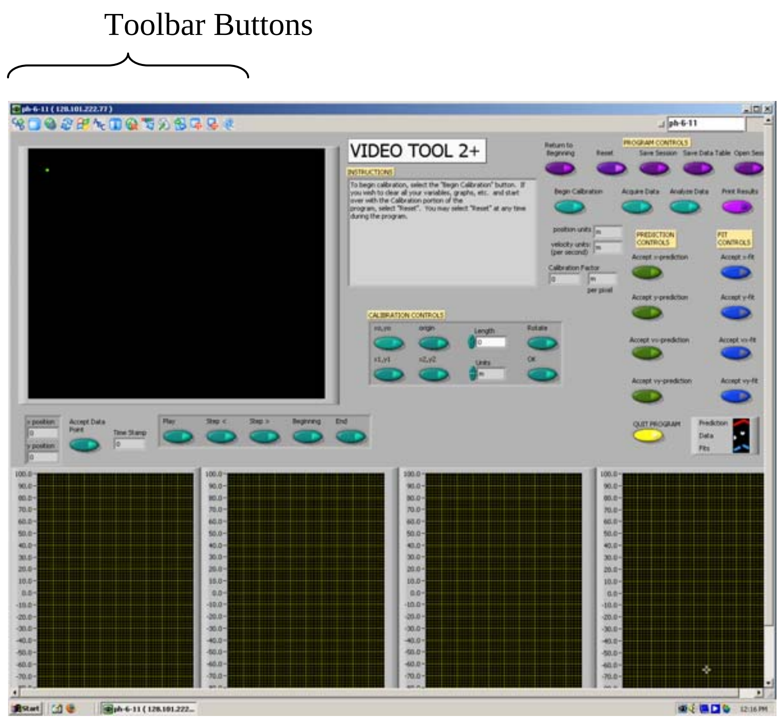


Fig. 4: Sample view of a student screen

Refer to Figure 4 for a sample view of a student screen. You can resize the window of the student screen using the arrows in the bottom right corner.

Use the toolbar buttons to navigate Ultr@VNC, as seen in Figure 5. Most buttons are self-explanatory, but selected descriptions are given on the next page.

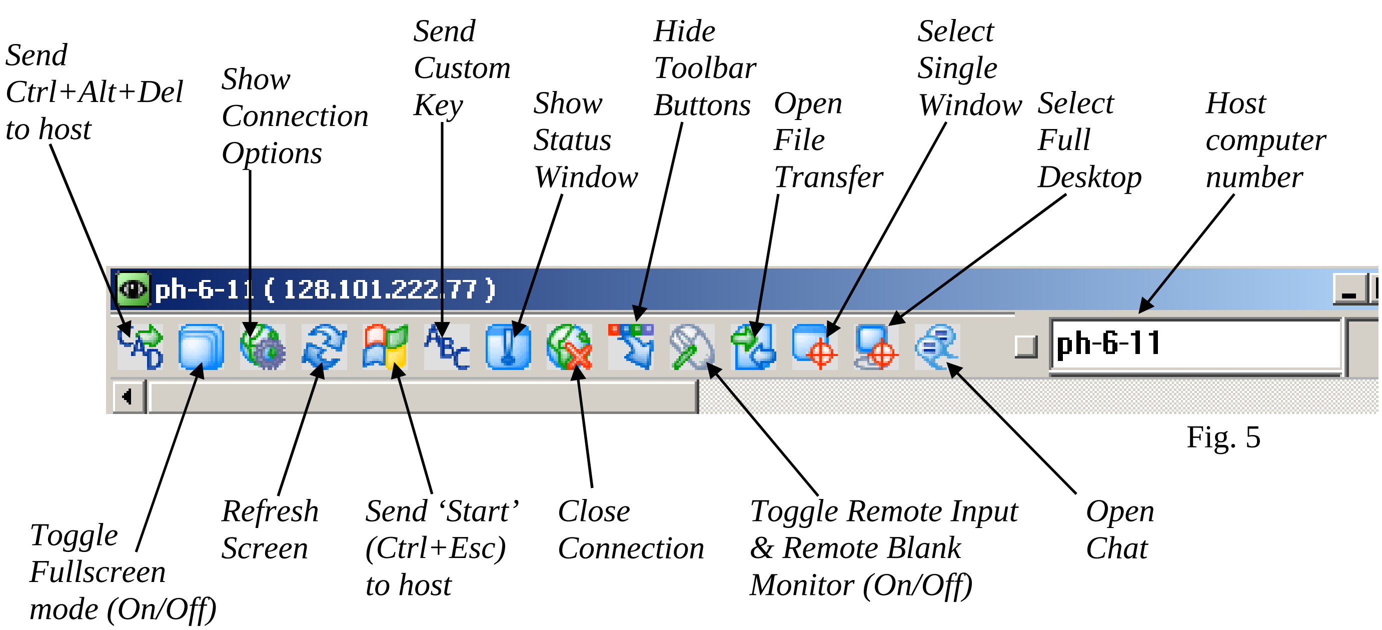
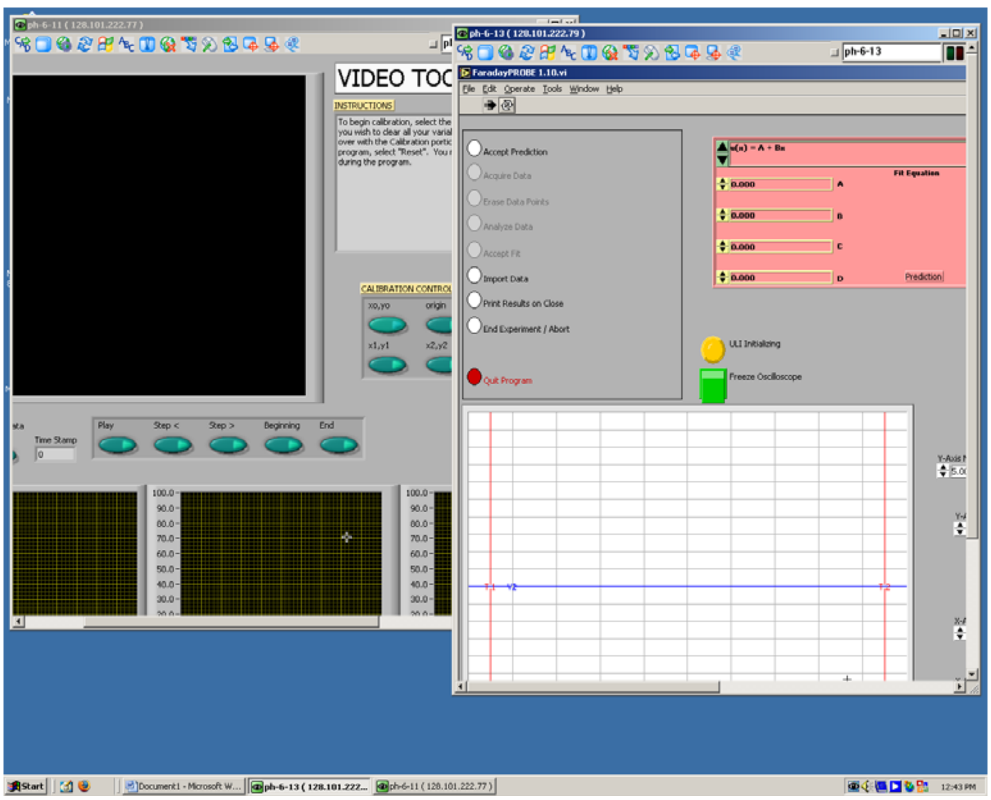


Fig. 5

Selected Descriptions for Toolbar Buttons:

- ***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).
    - There are three options for the *Mouse Cursor*: Track remote cursor locally, Let remote server deal with mouse cursor, and Don't show remote cursor.
    - The first two options appear to be a shared-control option between the student and instructor computers, with slight differences between what is seen on each screen.
- ***Toggle Remote Input & Remote Blank Monitor (On/Off)*** 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 fullscreen view, click the ***Select Full Desktop*** toolbar button.



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

Fig. 6

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

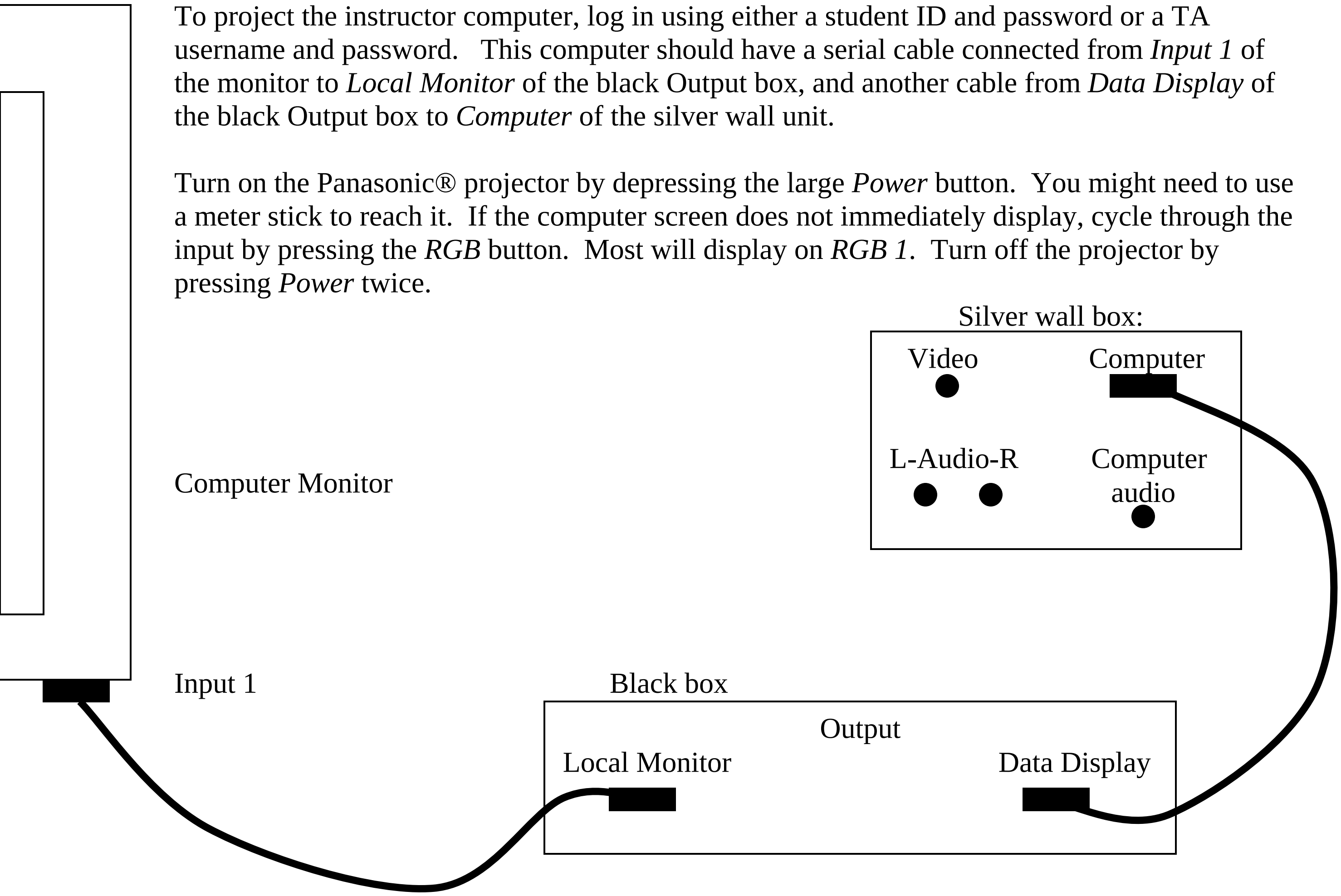
For more information, the software developers' website is:
http://www.ultravnc.com/

Digital Projector Reference:

Every lab room has a Panasonic® projector fixed to the ceiling with connections to a wall unit. This is useful to project documents or programs onto a pull-down screen for easy viewing by the entire class.

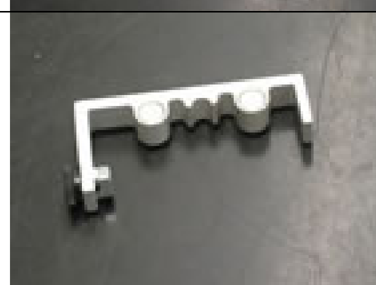
To project the instructor computer, log in using either a student ID and password or a TA username and password. This computer should have a serial cable connected from *Input 1* of the monitor to *Local Monitor* of the black Output box, and another cable from *Data Display* of the black Output box to *Computer* of the silver wall unit.

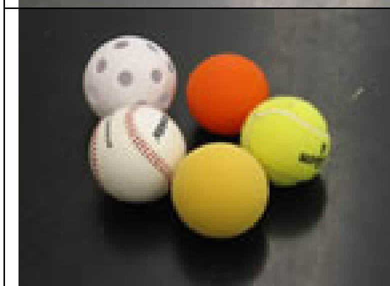
Turn on the Panasonic® projector by depressing the large *Power* button. You might need to use a meter stick to reach it. If the computer screen does not immediately display, cycle through the input by pressing the *RGB* button. Most will display on *RGB 1*. Turn off the projector by pressing *Power* twice.

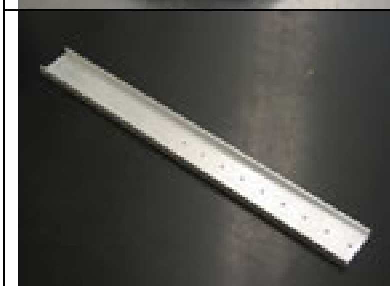
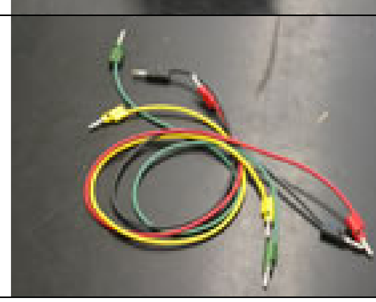
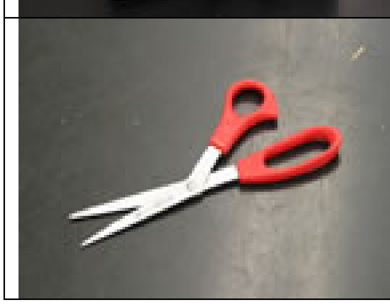


1301 Equipment Guide

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 and nuts and bolts should be securely tightened after use.** Common problems are noted for some equipment that might provide potentially quick fixes. Thanks for you help!

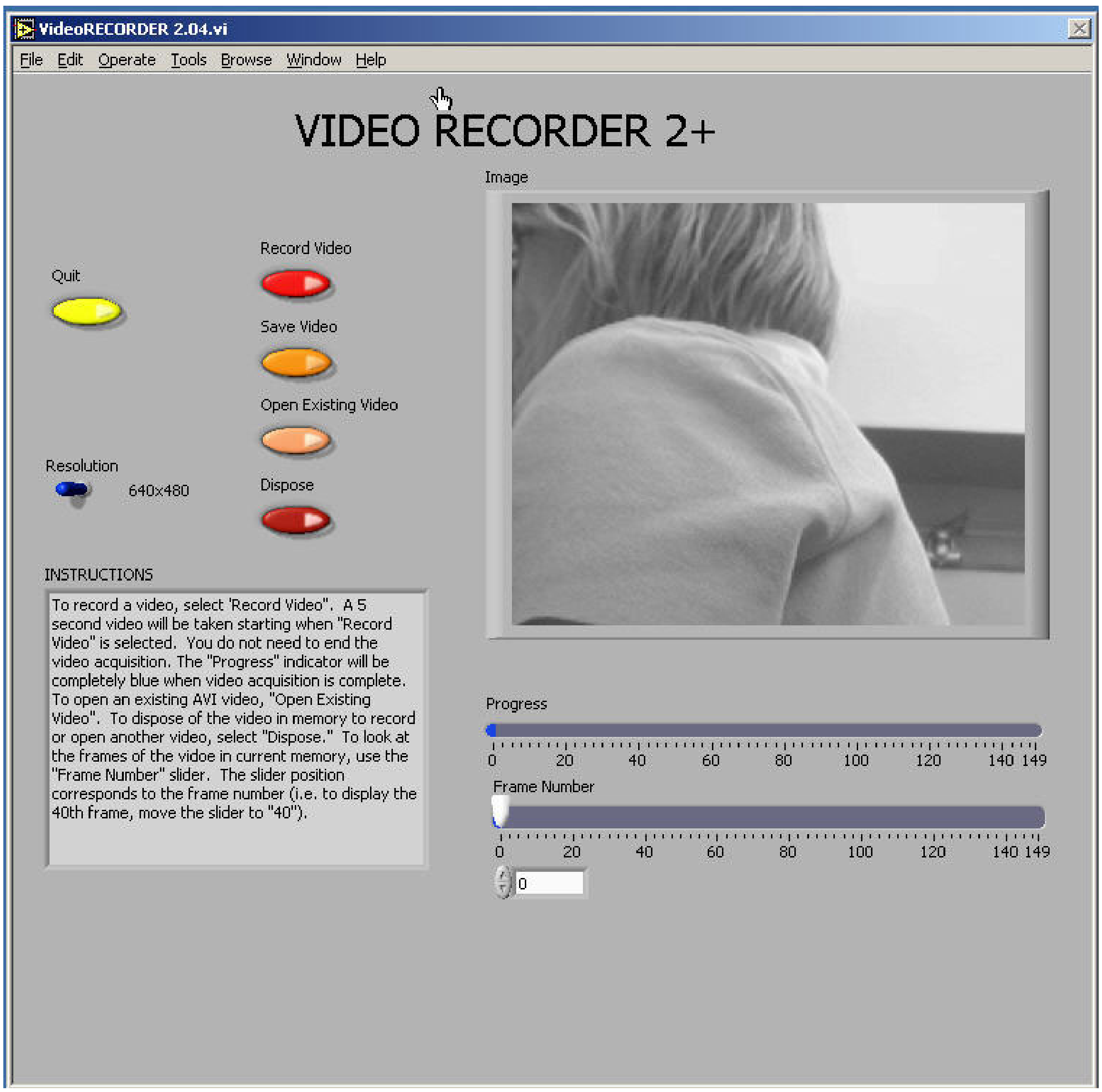
	**Toy Car** Replacements in second floor closet #8		**Track** Tracks are left in the labrooms.
	**Stop Watch** Replacements in second floor closet #8		**Meter Stick** Replacements in second floor closet #7
	**Video Setup – firewire camera and cable.** Replacements in second floor closet #8		**Endstop** Replacements in second floor closet #8 Keep lock screw tight.
	**Wood Block**		**Cart** Replacements in second floor closet #8

	**Cart Masses**		**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		**Mass Hanger** Replacements in second floor closet #8
	**Mass Set** Keep mass sets together as sets. (1x200g, 1x100g, 2x50g, 2x20g, 2x10g & 2x5g)		**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**		**Wood Dowels**
	**Aluminum (Crane) Channel**		**Springs** Replacements in second floor closet #8 Do not overstretch
	**Metal Rod**		**Mechanical Oscill0ator** Check the fuse
	**Function Generator**		**Banana Cables** Replacements in second floor closet #8
	**Scissors** Replacements in second floor closet #8		

Video Analysis of Motion

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 WindowsNT through the use of one such program: the 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.

(1) 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 on the previous page 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.

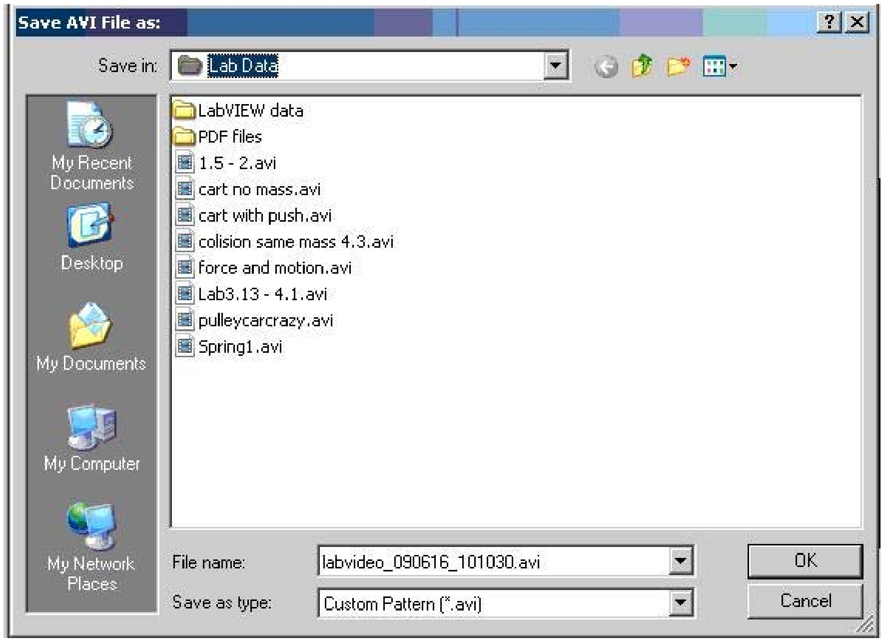
The controls are fairly self-explanatory; pressing the *Record Video* button begins the process of recording a 5-second video image. While the video is recording, the blue *Progress* bar beneath the video frame grows. Once you have finished recording, you can move through the video by dragging the *Frame 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.

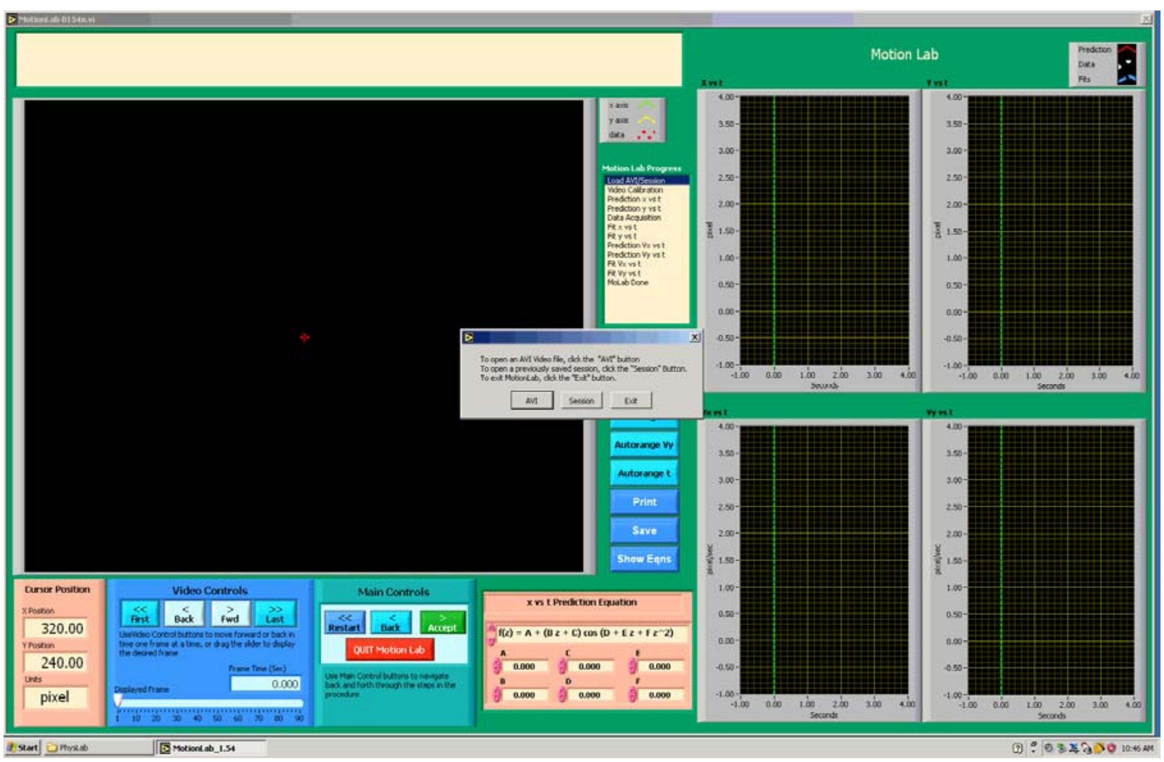
Once you have recorded a satisfactory video, save it by pressing the *Save Video* button. You will see a *Save* window, as shown on the next page.

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).

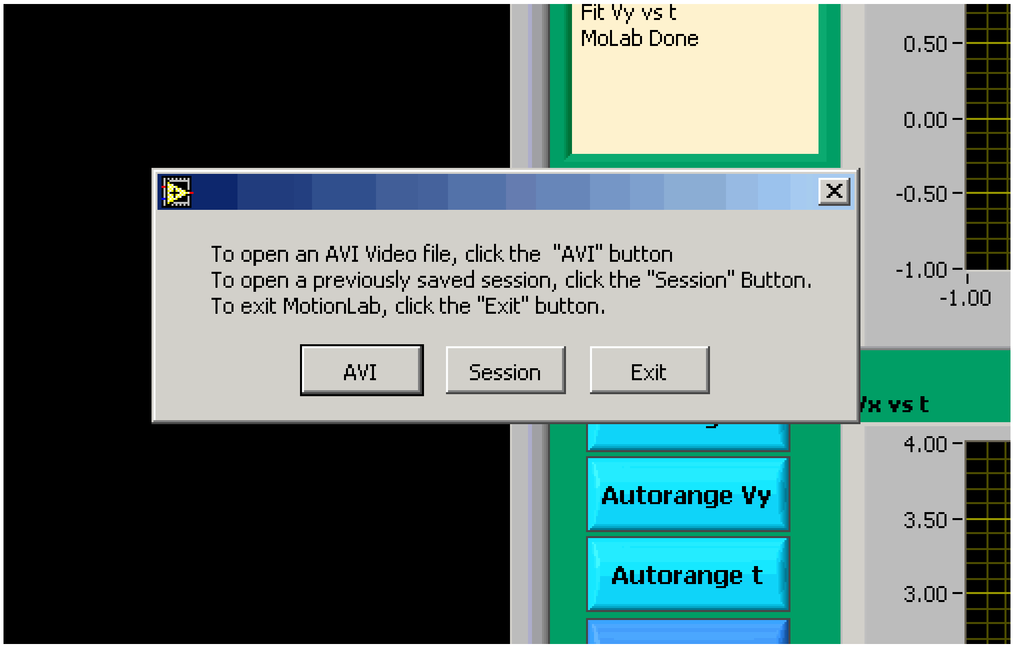


(2) ANALYSIS BASICS

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

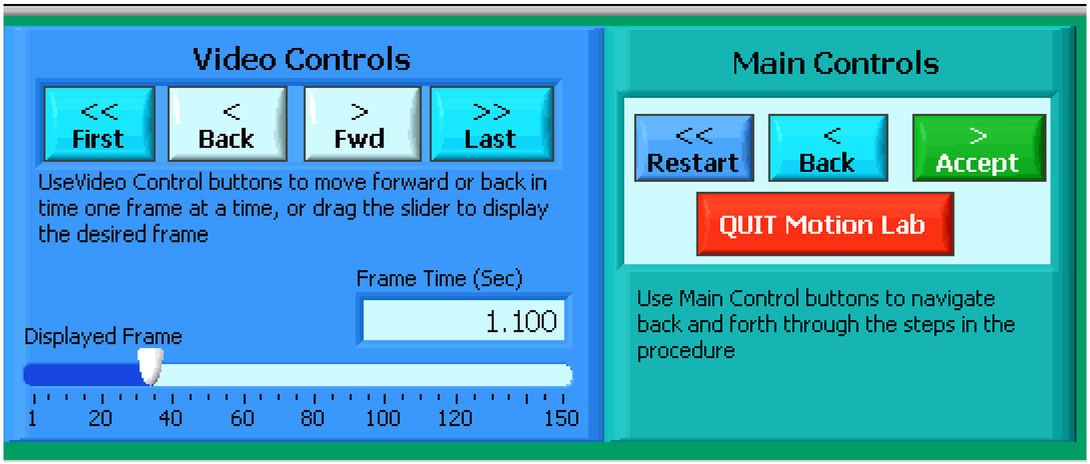


The application will prompt you to open a movie (or previously saved session) as shown below.

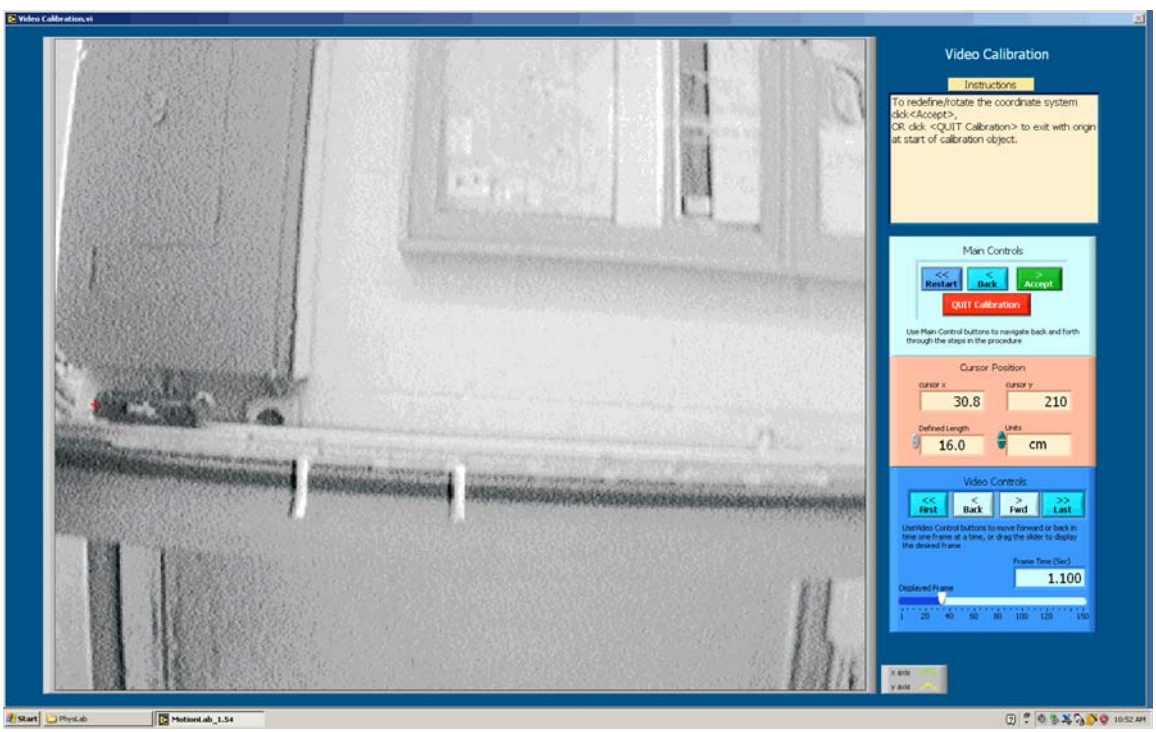


The upper left corner displays a dialog box with instructions for each step during your movie analysis. To the right of the video screen is a progress indicator. It will highlight which step you are currently performing.

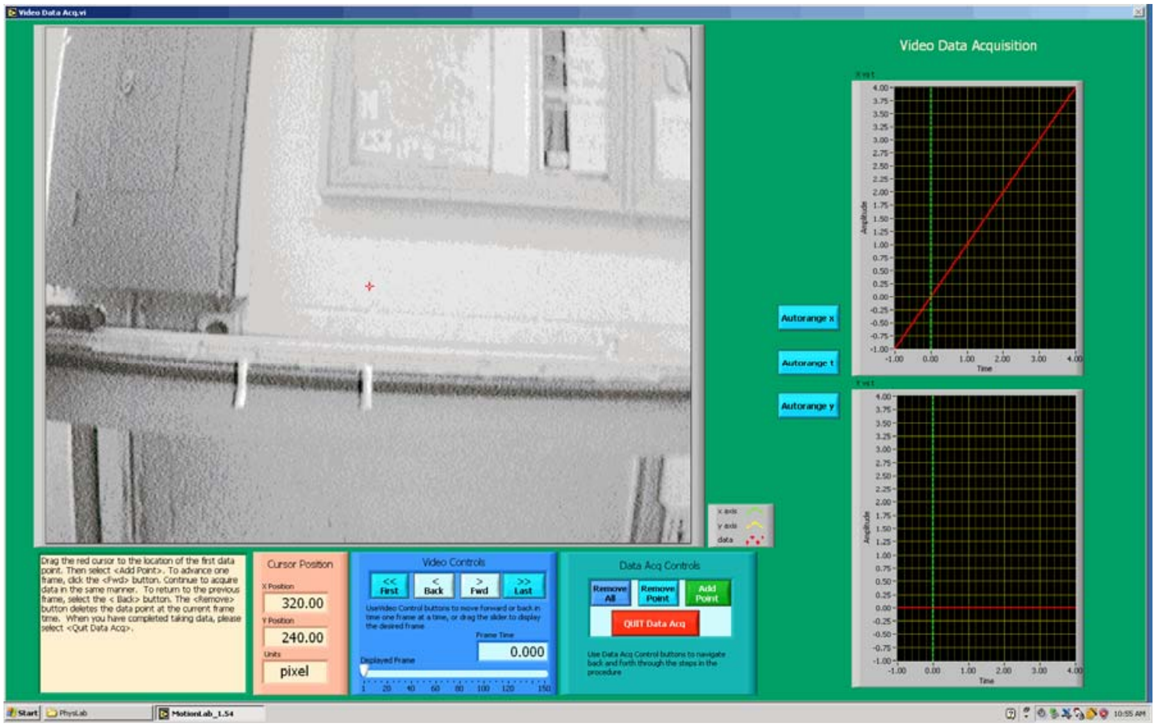
Below the video display is the Video Controls for moving within your AVI movie. The slider bar indicating the displayed frame can also be used to move within the movie. Directly to the right of the Video Controls is the Main Controls. The Main Control box is your primary session control. Use the Main 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.

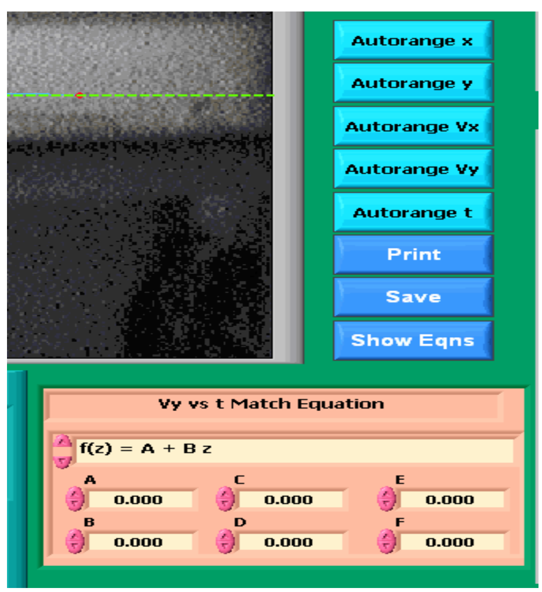


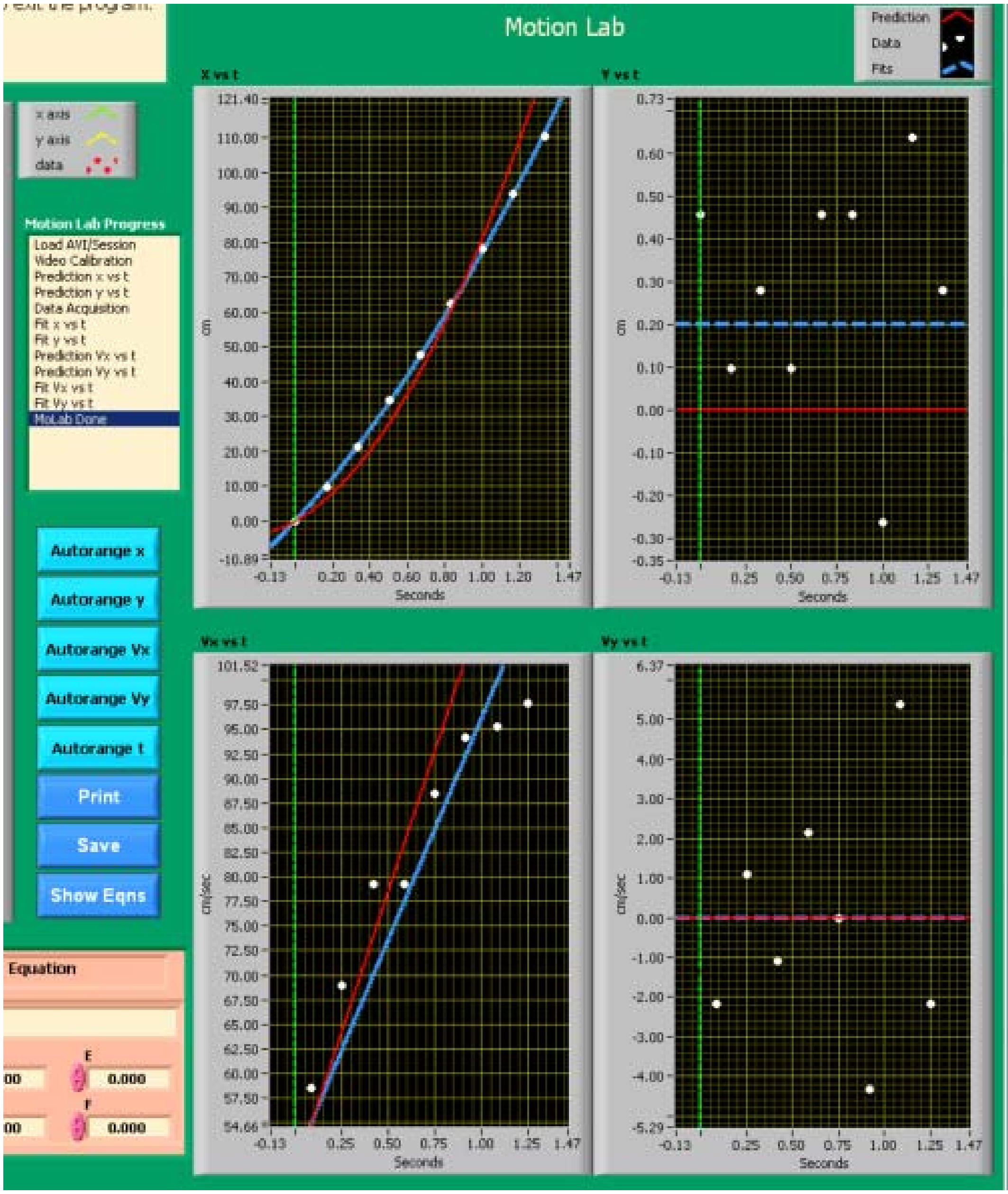
The data acquisition screen is shown below. To get to the data acquisition screen you need to first enter predictions (the progress indicator will display which step you are at.) More will be said about predictions in a bit. The data acquisition screen has the same instructions box and Video Controls, 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 on the next page. 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.

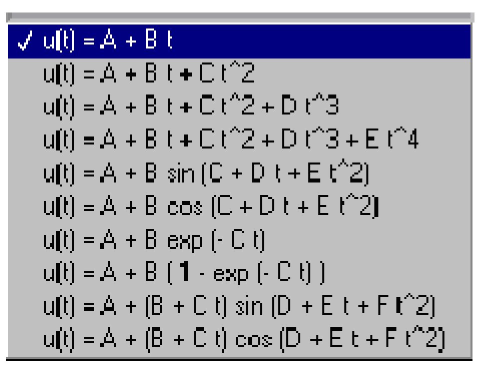
ANALYSIS PREDICTIONS

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? This happens so often that it is given a name (Murphy's Law). 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*. 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 Data 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 *ADD Data 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* from the *controls*

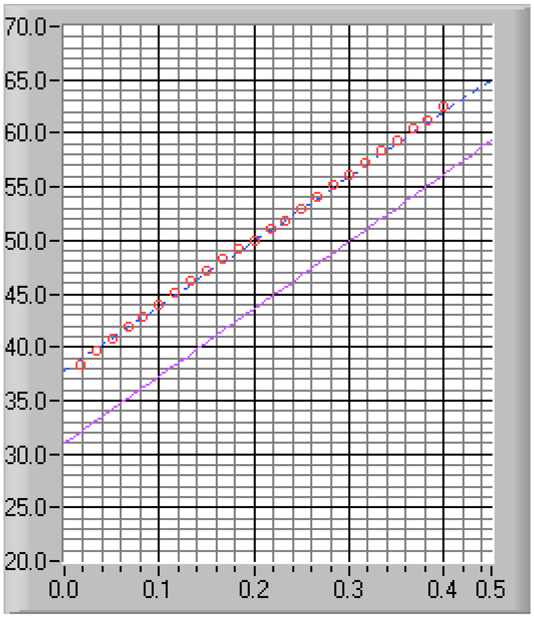
FITTING YOUR DATA

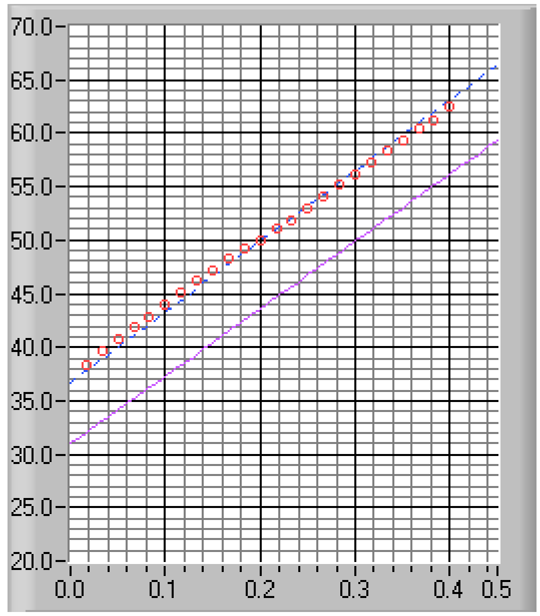
Deciding which equation best represents your data is the most important part of your data analysis. The actual mechanics of choosing the equation and constants is similar to what you did for your predictions.

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.

Secondly, 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.

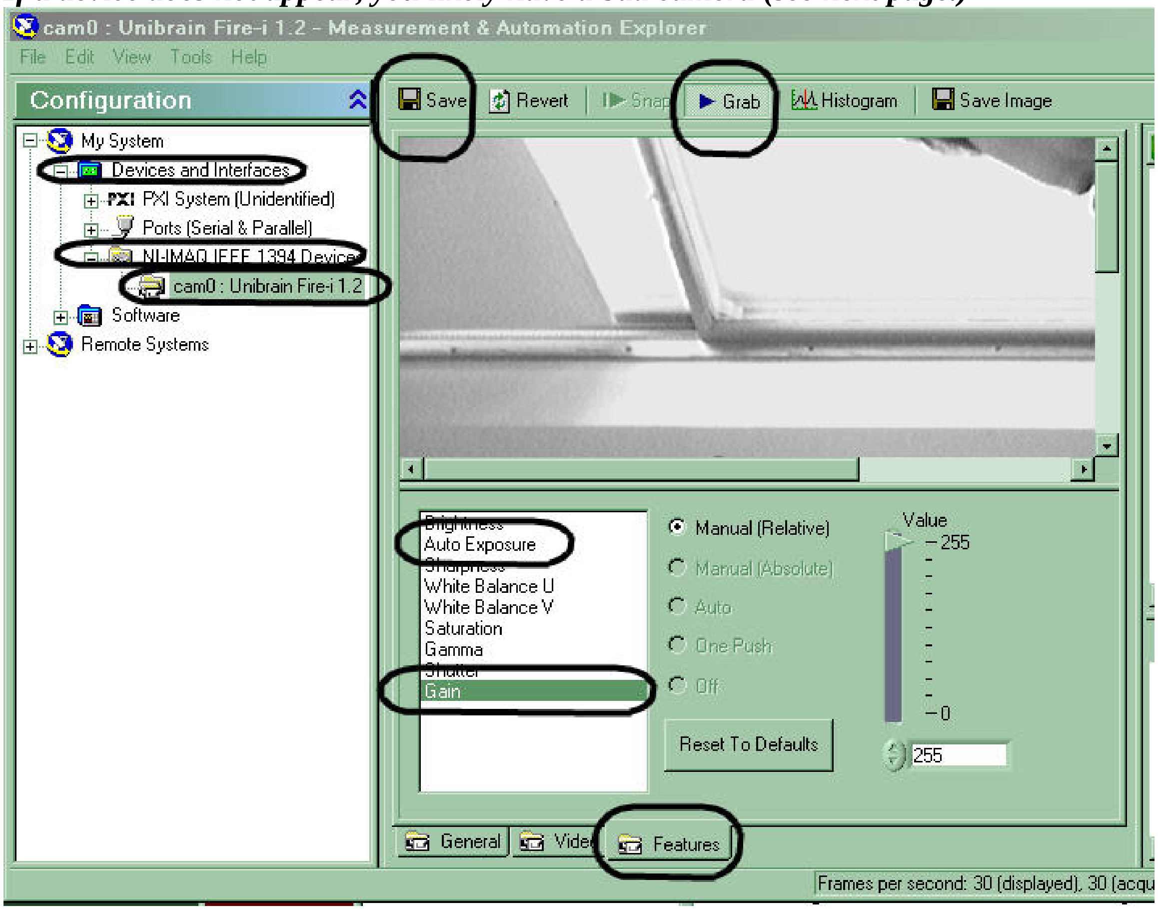
LAST WORDS

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.

To install a camera:

1. Hook up new camera to firewire cable.
2. Launch the "Measurement & Automation" application (icon on desktop)
3. On the left-hand panel *(shown below)*, expand "Devices and Interfaces"
4. On the same panel, expand "NI-IMAQ IEEE 1394 Devices"

MAX has a generic camera setup initially; this needs to be switched to the Unibrain camera by right clicking on the device and selecting the NI-IMAQ driver using the menu. ***If a device does not appear, you likely have a bad camera (see next page.)***



5. On the same panel, click the icon for the camera ("Unibrain cam0:…")
6. Click GRAB *(along the top, shown above)* to see what the camera sees
7. Click the Video tab (*along the bottom, next to the circled features tab*)
8. Change Video Mode by selecting the last option in the pull down menu (640x480 Y (Mono8)(30fps))

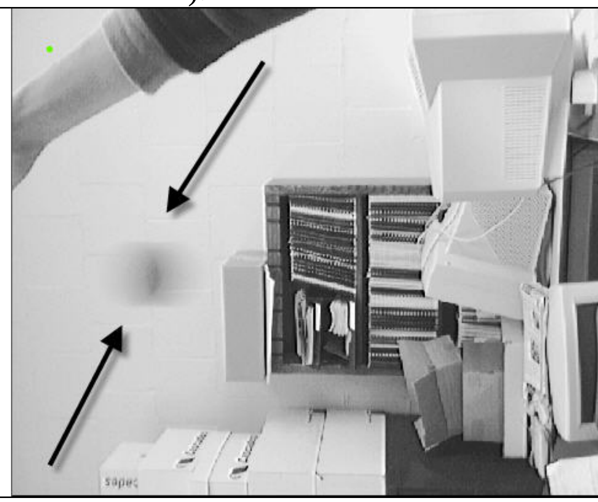
To help your students get useful data from the video camera, it may be necessary for you to adjust additional camera settings. (These settings should be stable, but may change when a camera is unplugged from its computer.)

9. Click the FEATURES tab (*along the bottom, shown above*)

In the picture below, "gain" is selected, and is set to its maximum value of 255.

10. **Set GAIN to its MAXimum value (this may cause a "washed-out" image).**
11. **Set AUTO EXPOSURE to the MINimum value that shows a useful image (depending on camera and lighting, 180 or below may be possible).**
12. Click SAVE (*top left*) to save the settings.
13. Exit the "Measurement & Automation" application.

To install a camera:

“Good” camera settings	**“Bad” camera settings (factory default)**
• short Exposure time • high amplification (Gain) Motionless objects may look grainy; objects in motion have well-defined edges (The ball below has fallen through the entire frame).	• long Exposure time • low amplification (Gain) Motionless objects look nice; motion causes blur (The blurred ball below has fallen only a short distance).
	

To check to see if a camera is bad:

1. Hook up camera to firewire cable.
2. Launch the <u>“Measurement & Automation</u>” application (icon on desktop)
3. On the left-hand panel, expand <u>“Devices and Interfaces”</u>
4. On the same panel, expand <u>“NI-IMAQ IEEE 1394 Devices”</u>

If a device (camera) does not appear, you have a bad camera, cable or firewire card. Check the cable, making sure the connectors are intact and not plugged by debris. Look at the firewire card in the back of the computer - try to use the port that looks best. If the camera still does not work, get a new camera and start over. If the new camera doesn’t work, reboot the computer and try again, possibly with a third camera. You can also use the TA computer and see if the camera will work on that machine. Remember to submit an electronic lab problem report form about any unresolved problems and bad cameras.