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INTRODUCTION

As a TA in the laboratory, you want to make sure that students complete their tasks and benefit from their experience. You must make many decisions about how to best navigate your students questions, frustrations, and learning process. You need to be able to see when a student or group needs assistance because they are stuck or if they need space to figure it out with their group. This instructor guide is meant to help you become a better coach to your students. However, 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 and try to understand what your students may be confused by. Also, do not let students see this instructor guide – their discovery of the solution is the essence of their learning.

Please report issues you find to improve the instructor guide:

- Typos and/or incorrect or unclear statements in the student manual
- Errors or incorrect references in the Instructor Guide
- Notes on the new labs ESPECIALLY focused on:
    - The students' understanding of the material
    - The students' ability to make it through the lab within the allotted time
    - How well the data worked for the whole class

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.

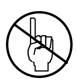
2. Always tell students explicitly that they should hand in answers to both the Predictions and Warm-up questions for the problem(s) that you assign before they come to lab. The deadline for handing them in will be decided in your teaching team – it is usually 1or 2 days before the lab session. *Make 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.

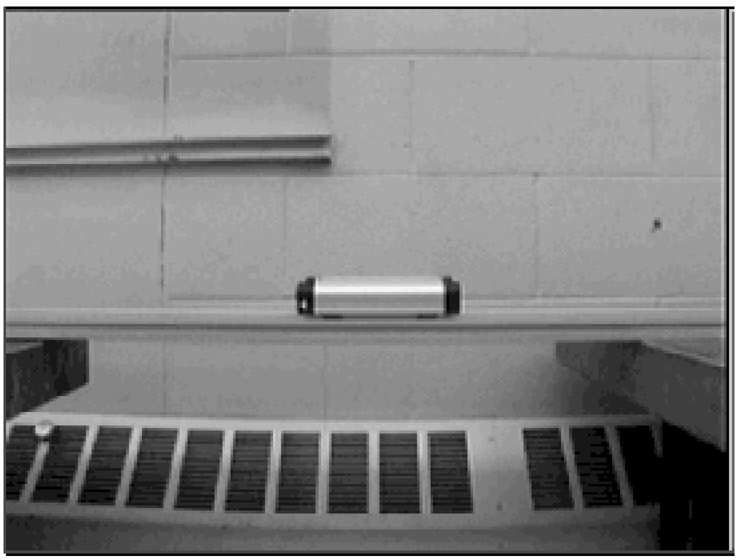
4. Some suggestions about the camera and video analysis program:
- The computer will skip fewer frames if the background of a given movie is free from clutter.
- Take a few moments to learn how to focus the camera with the zoom feature. The zoom adjustment is at the end of the lens, while the focus is near the base.
- The object the students use to calibrate their movies MUST be in the plane of motion of what they are measuring.

- 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. 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:

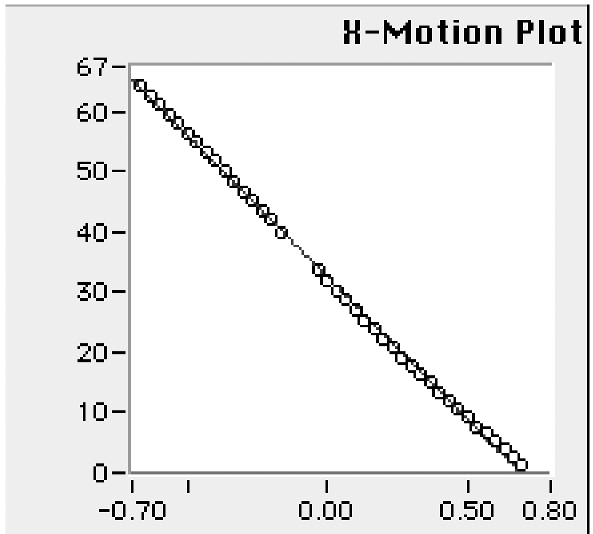
- The camera is not level with the cart's motion. The video is shot from above, which causes the cart's image to be distorted. Notice that the right side of the cart is visibly closer to the camera than the left side. Thus our 2-D picture has a 3-D component for which we cannot account – this will cause 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).

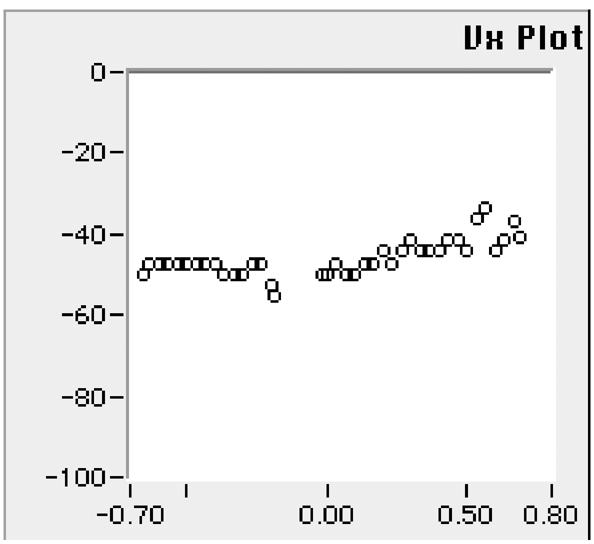
Analysis of our movies

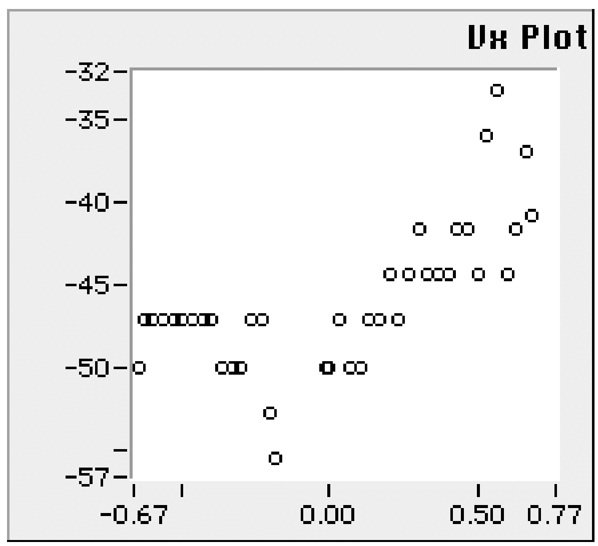
Here we analyze the movies. The motion is that of a cart moving with constant velocity along the track. Although the velocities are different, we can still use the movies to compare what are considered good results with those that are bad.

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.





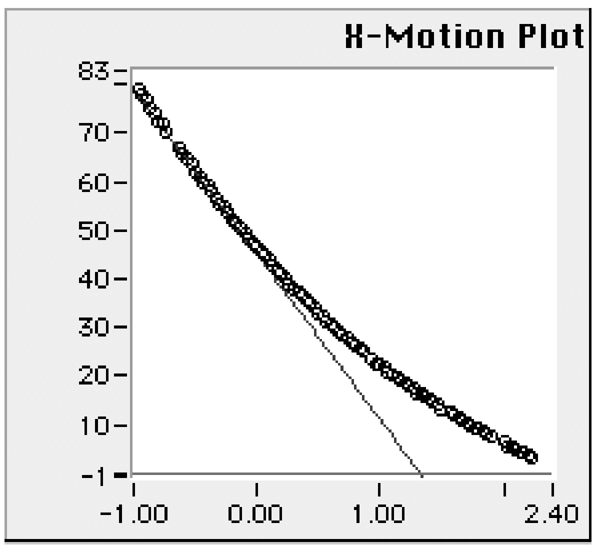


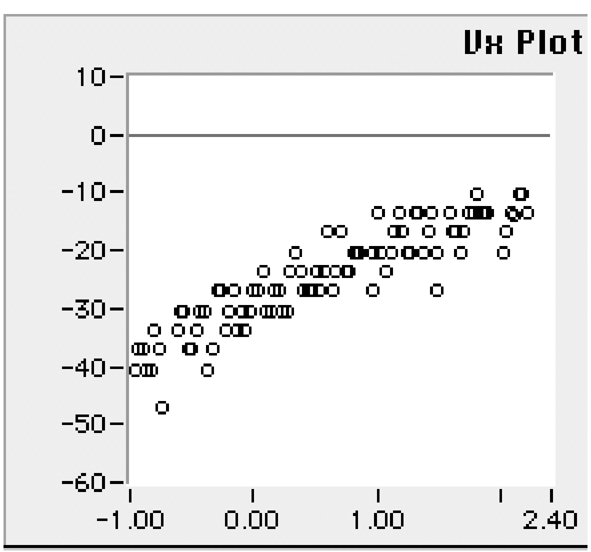
We include two velocity-versus-time graphs for the good movie. In the plot on the left we put in the axis limits ourselves. The plot on the right is "autoscaled." (Both plots are identical except for the y-axis scaling.) We include both graphs to show how "autoscale" may mislead the students into thinking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

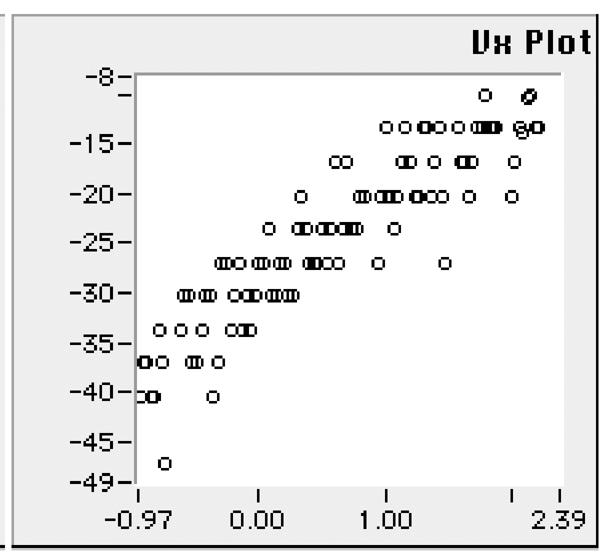
You may have noticed that some of the data points were taken at "negative" time (the horizontal axis is the time axis). This is due to the fact that we forwarded the movie to the frame in which the cart was at the center of the screen to do our calibration. We then reversed the movie so we could start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

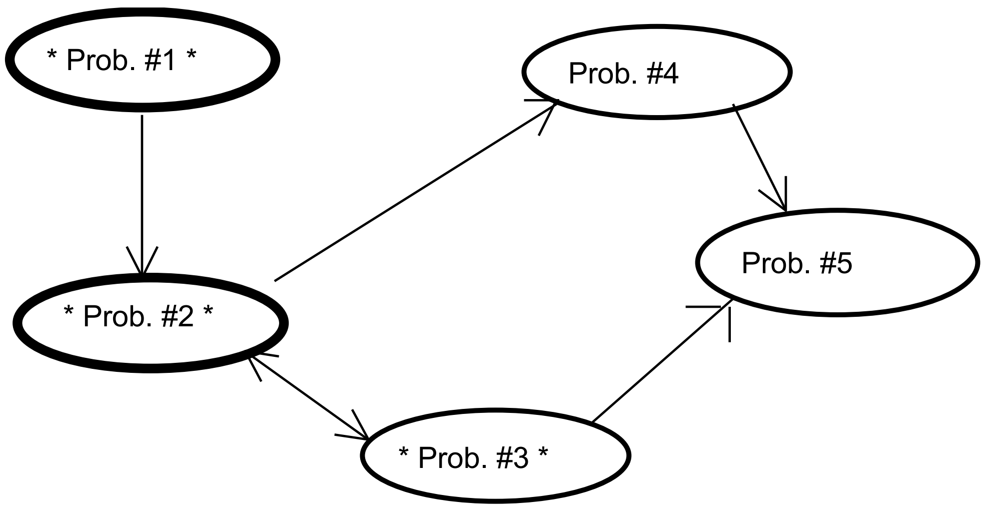
The range of available problems allows you to assign tasks to groups that reflect the needs of the students in that individual group. Some problems are basically repetitions of a previous problem for those groups who you judge do not quite understand the central idea of the lab. Others are challenging 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 1: Description of Motion in One-Dimension

Ignoratu motu,
Ignoratur natura.

Greek philosophers claimed that ignorance of motion meant ignorance of nature. Therefore, studying objects in motion was the best way to learn about the natural world. Laboratory 1 considers motion in its simplest manifestation, one-dimensional motion.

Lab 1 contains 5 problems. The first week will be especially slow because students are learning to use the equipment and computer software for the first time. In a team meeting you should decide on the problems you will assign to your students. The first and second problems (constant velocity and constant acceleration) are the most important, and they must be completed by all groups.



Teaching Tips:

1) **Avoid talking about calculus.** Students will know how to graph a curve and find the slope, but they don't actually need calculus for this course and may have never taken it thus may be very intimidated if you mention it. If you want to talk about derivatives or integrals, do so only with geometric language (i.e. slopes and areas under the curve). In the 1101 physics, we ask students to start with a graph of velocity versus time, and then work all the subsequent graphs. Make sure that students see the connections between these graphs.
2) **Save your discussion of forces.** This is only the first lab. Forces will be introduced later. Now you are only describing the motion, not explaining why there is a motion.
3) **Spend time looking at Warm-up questions and predictions.** Students know how to hide their confusion. Take time to discuss what they think might happen.
4) **When you are asked a question, turn the question back upon the student.** (e.g. Do you think that is an important quantity to measure? Is that the best way to view your data? What does the manual suggest?)
5) **Be social.** Once the groups are off and working, don't just sit at the front of the room and wait for questions. Float amongst the groups, ask the students what they have learned, ask where their difficulties lie. Students are more apt to voice their questions in a group. It helps if you confront them in their setting.
6) **Acknowledge their uncertainties.** If physics is required for a students program, it is highly likely to be the most difficult and frustrating class that they will take. The fact that you know the subject so well may be intimidating. Be as APPROACHABLE as you possibly can. When students trust you, they will be more likely to try.

Things to Remember:

1) Email labhelp@physics.umn.edu with all equipment.
2) Remind the students to write down the equations in the prediction and fitting steps before they proceed to the next step, you never know when a computer might hang or crash.

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

1) Use the concepts of position, time, velocity, and acceleration to completely describe the motion of an object moving in one-dimension.
2) Distinguish between the average and the instantaneous velocities and accelerations of an object in motion.
3) Express the mathematical relationships between position, time, average velocity, and average acceleration.
4) Use graphs to analyze the motion of objects in one-dimension.
5) Learn the rudiments of technical communication by keeping an accurate journal and writing a laboratory report.

Things to check fifteen minutes before lab:

1) See how fast/ hard you can safely push the carts.
2) See how slowly/ softly you can push then and get reasonable results.
3) Determine the best settings (height, focus, brightness, etc.) for the camera.
4) Find out what range of angles gives the best results for motion up/ down an incline.

Lab 1 Problem #1: Measurement and Uncertainty

There are several goals of this exercise:

1) Give the students experience measuring things and calculating the uncertainties of their measurements
2) Give the students a guided exercise so that they can develop their ability to work in groups by organizing tasks and discussing what they think
3) Practice fitting equations
4) Use the computer analysis software and make a connection with what their data physically means

What YOU as the TA need to emphasize:

1) Discussion, discussion, discussion! Get them use to sharing ideas with each other before they ask you
2) Keep them from rushing through things AND from going too slowly. You have to monitor the groups' progress because they must get through the whole lab to have the video analysis experience.
3) Wander around and talk to the groups. Even if they don't have questions, stop them and have them explain what they are doing and why. This is the time to set up the protocol for the semester.

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

1) Dress nicer than you normally do for the first two weeks. It helps the students see you as an authority and take you seriously
2) Present the lab rules and protocol clearly. Even though you will give exceptions to certain circumstances as they come up, you need to state what will be expected of the students.
3) Get them to ask questions. About anything. While you want to be taken seriously, you also want them to see you as someone that can help them when they are confused.
4) Start using their names right away. Guess if you don't know. You are allowed to make mistakes in the first couple of weeks. They will appreciate that you are trying.

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;
- the dependence of graph shape on function type;
- the 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. All of the "Mystery Functions" are described in the table, but they will only need to practice with Functions 1-4 since those are the pertinent equations to this class.

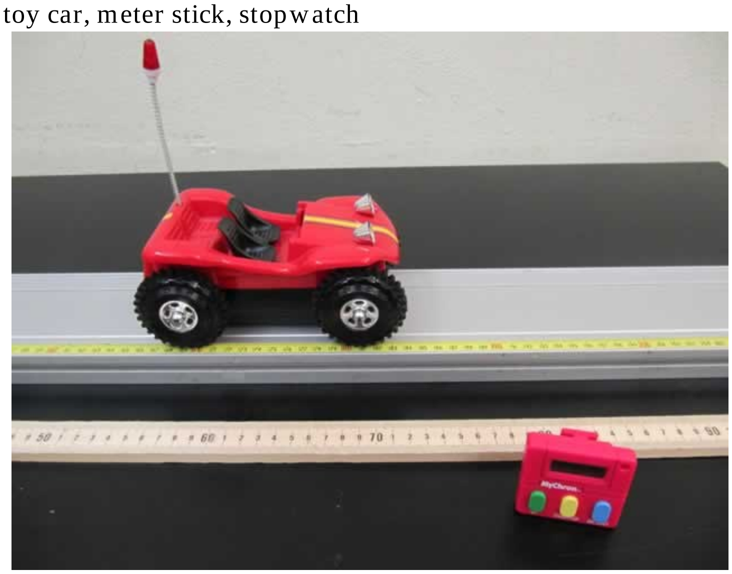
Mystery Function	COMMENT / Details
1	SIMPLEST / Linear; u(t) = A + Bt; A is random integer in [-5,5]; B is random half-integer in [-2.5,2.5]
2	ALWAYS FORCES STUDENTS TO ADJUST AXIS SCALES / Linear; A is decimal in [-24.0,-15.0] or [15.0,24.0]; B is decimal in [-5.0,5.0]
3	PARABOLA, SYMMETRICAL AROUND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

Constant Velocity Motion

Purposes:

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

Equipment: track, toy car, meter stick, stopwatch



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.
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.
3) Students become overwhelmed by the computer and forget the purpose of this lab. You will need to remind them that they are looking for the effect of the lens distortion.
4) When the students use the video analysis software to examine the motion near the left and right sides of the video image and find velocities in this region, they should see a dramatic effect. The apparent velocity near the edges of the video image in one case was measured to be about 25% less than the actual velocity seen in the middle of the image. This percentage will vary, depending on how much care the students put into making their movies.
5) You should suggest to your students that they should investigate the upper and lower regions of the screen along with the left and right. This is their chance to understand the limitations of the camera. If they don't understand these limitations, they are certain to have difficulties later in the semester. You may want to have them make "good" and "bad" movies and compare them.
6) 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.
7) 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.
8) Make sure everyone in each group gets the chance to analyze a movie. There tends to be at least one "computer-hog" per group and some students will be left out unless you intervene.

Difficulties and Alternative Conceptions:

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

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

Prediction and Warm-up Questions:

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

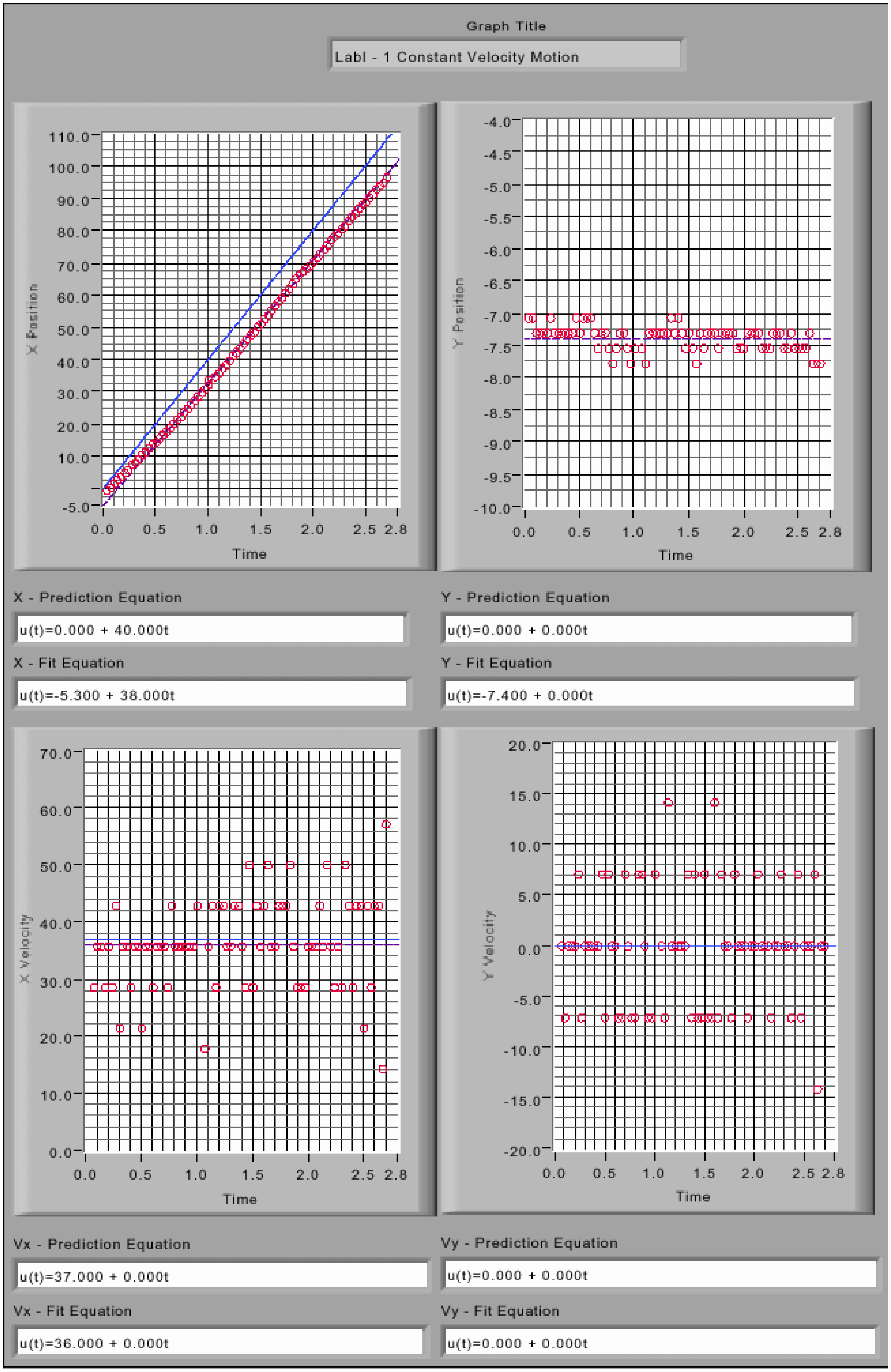
(Note: In all cases the prediction and Warm-up questions are your responsibility. You must complete them on your own in preparation to teach. Only for the more complex labs will this guide provide you the answer to the prediction. Use this guide as a check to make sure your work is correct.)

Possible Discussion Questions:

1) What is the best range of velocities to study on this track?
2) Is this a useful model of the automobile race situation that we are studying?

Sample Data:

Velocity of Toy Car is about 37cm/ s.

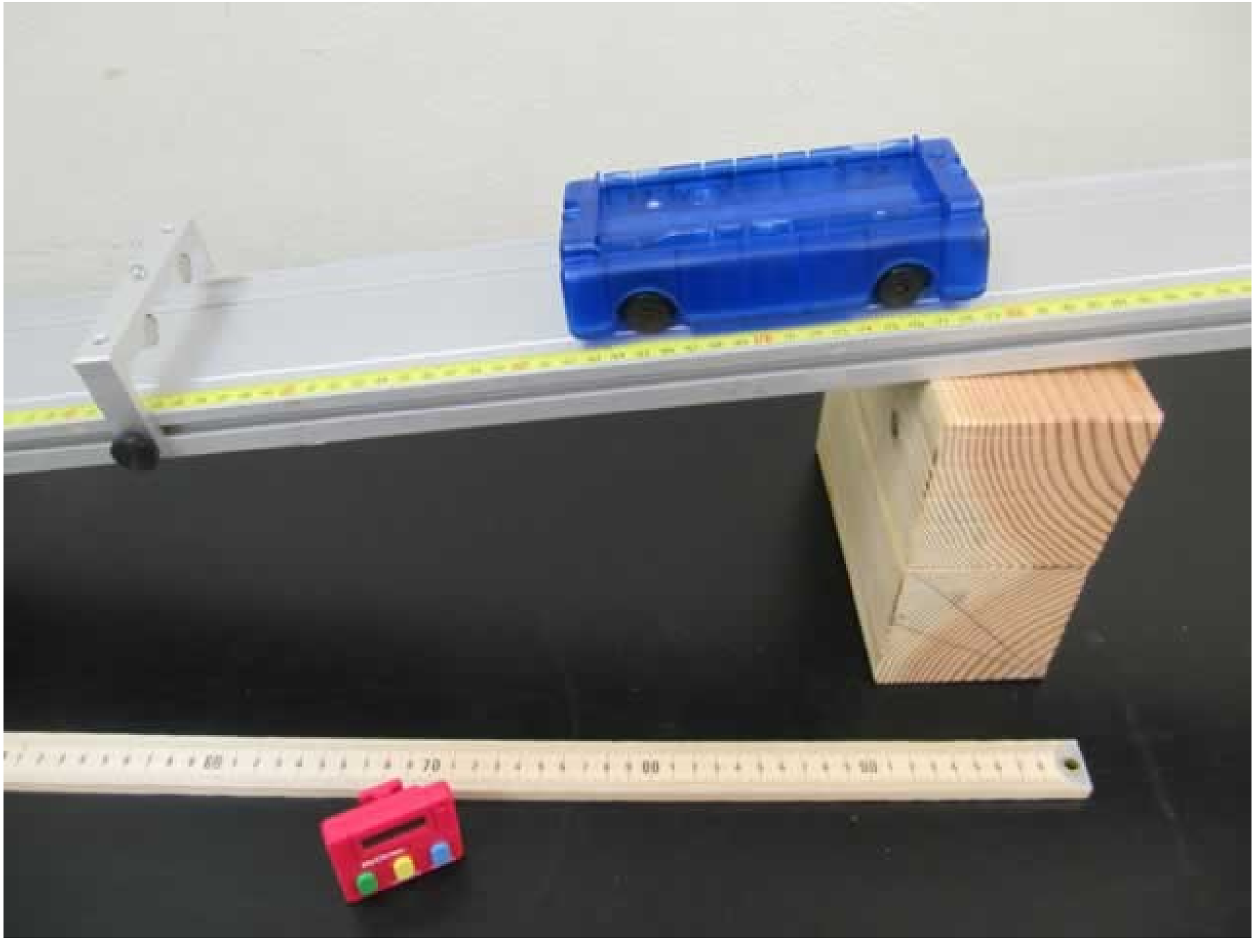

Graph Title
Labl - 1 Constant Velocity Motion
X Position
Time
Y Position
X - Prediction Equation
u(t)=0.000 + 40.000t
X - Fit Equation
u(t)=-5.300 + 38.000t
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-7.400 + 0.000t
X Velocity
Y Velocity
Vx - Prediction Equation
u(t)=37.000 + 0.000t
Vx - Fit Equation
u(t)=36.000 + 0.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

Lab 1 Problem 2: Motion Down an Incline

Purpose:

1) To reveal the constant, nonzero acceleration of a cart down an incline.
2) To recognize that $v_{ave} \neq v_{instantaneous}$, but that $a_{ave} = a_{instantaneous}$.

Equipment: track, end stop, cart, wood block, meter stick, stopwatch



Teaching Tips:

1) Every group should do this problem. Fitting 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 fit 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) It may be instructive to have the students print out the data table, then use the position and time data to create their own velocity-versus-time graph. The students should 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 for alternative conceptions. Ask students if you can have velocity without acceleration, acceleration without velocity.

Tell them that our bodies are acceleration detectors. We can feel acceleration, but cannot necessarily feel constant velocity motion. Get students to use the vernacular as much as possible. If they practice saying these terms they will understand test questions better.

Prediction and Warm-up Questions:

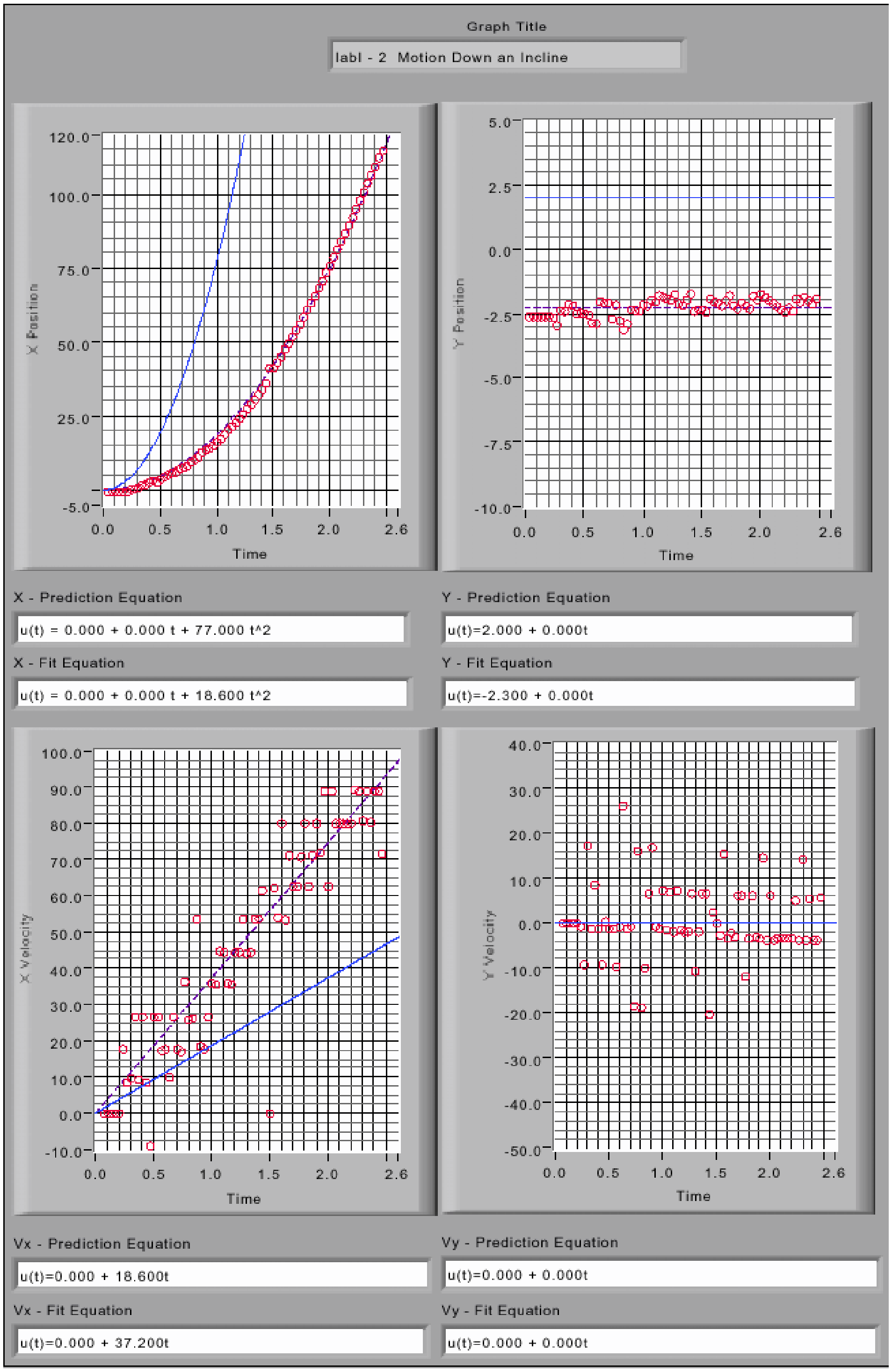
The prediction and Warm-up questions are straightforward and the prediction does not require any derived equation.

Possible Discussion Questions:

1) Is this exercise a good model for judging the safety of a roller coaster car track?
2) If the track were extended out to infinity, would the cart eventually reach infinite velocity?
3) As your car accelerates *forward*, how come you feel like you are being thrown *backward*?

Sample Data:

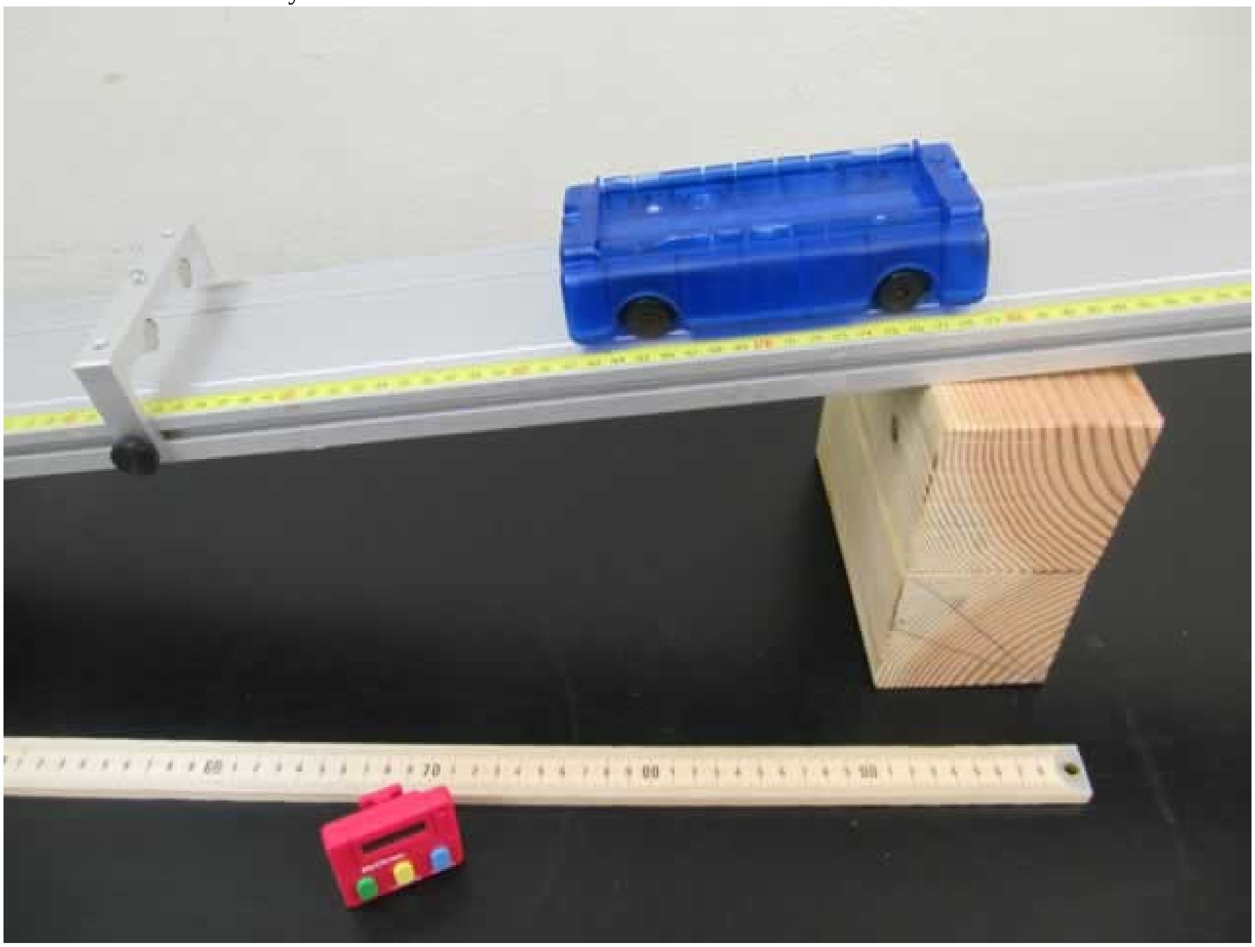
Inclined angle: $\sin^{-1}(8.7/ 220.5)$=0.39 rad = 2.26 degrees;
Acceleration: a = g sin (angle) = 37.2cm/ s^2.


Graph Title
labl - 2 Motion Down an Incline
X Position
Time
Y Position
Time
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
Time
Y Velocity
Time
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

Lab 1 Problem 3: Laboratory Extension- Motion Down an Incline with an Initial Velocity

Purpose:

1) To have the students discuss in their group what affect the initial velocity has on the acceleration of the cart without doing another lab.
2) There are Warm-up-like questions to lead the students through the different scenarios of having an initial velocity.



Teaching Tips:

1) This is a great time to help the students practice their discussion skills. You MUST make sure they come to the right conclusion! Also, make sure that it is not only the loudest, most insistent student that gets to talk.
2) Monitor the discussions actively! Jump in and make sure that they are considering all possibilities. Push back on all of their ideas whether they are right or wrong.
3) Use questions such as, "Why do you think/say that?", "How are you sure about that conclusion?", "Does your idea work in all situations?", "How can you confirm this idea?"
4) This problem is good for students who do not yet understand that velocity and acceleration are independent.

Difficulties and Alternative Conceptions

- The alternative conception is that the faster cart will have a larger acceleration. Make sure students break this misunderstanding before they complete the lab.

Important: if there is a group that does not agree, have them discuss how to use the video to support their idea. *Hint: they can take a video, skip all predictions and the position-fits. Just have them focus on the instantaneous velocity vs. time graph. They must get the right answer here, so make sure there discussions are productive.*

Possible Discussion Questions:

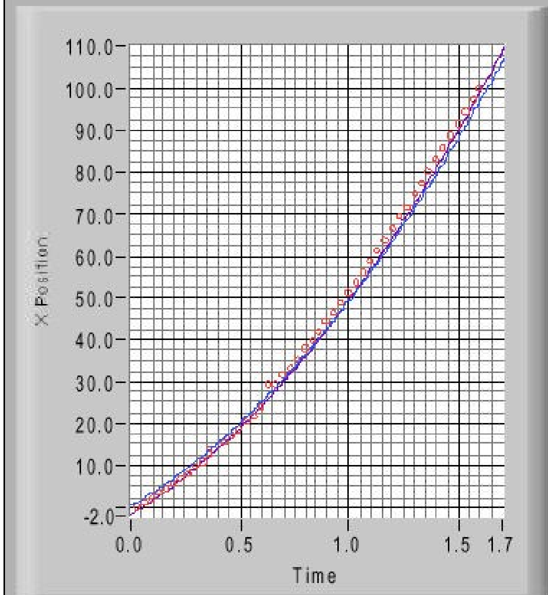
1) Remember the velocity limits you found in Problem 1? Were you extending these limits in taking data for this problem?
2) Does a running start help a bobsled team accelerate any faster? Does a running start decrease their total time of descent?

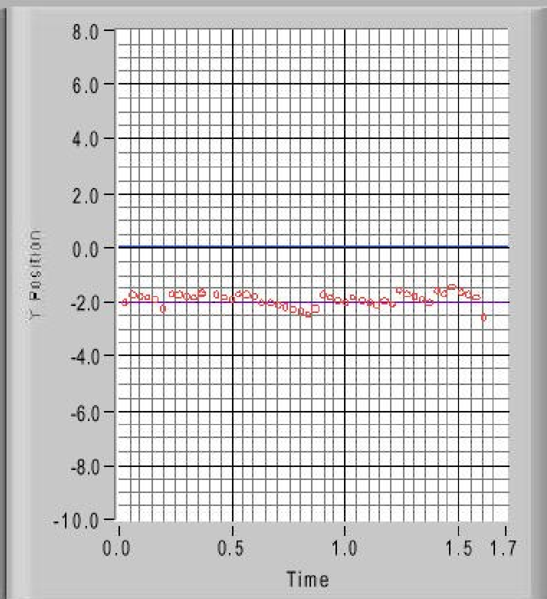
Sample Data:

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

Graph Title

Labl - 3 Motion Down an Incline with an Initial





X - Prediction Equation

u(t) = 0.000 + 30.000 t + 19.000 t^2

X - Fit Equation

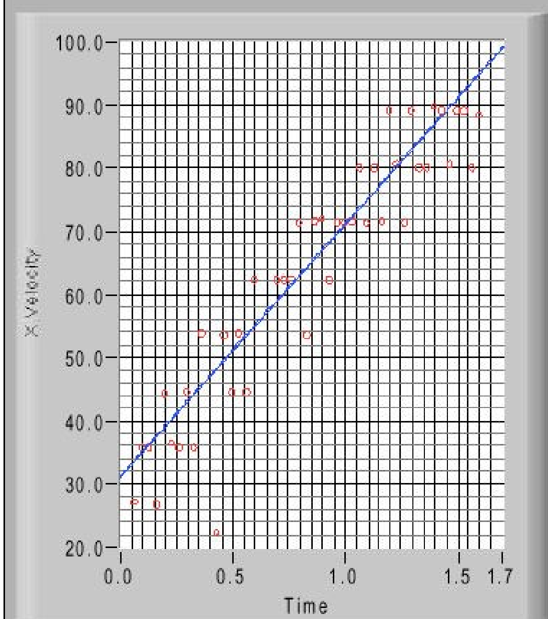
u(t) = -2.000 + 31.000 t + 20.000 t^2

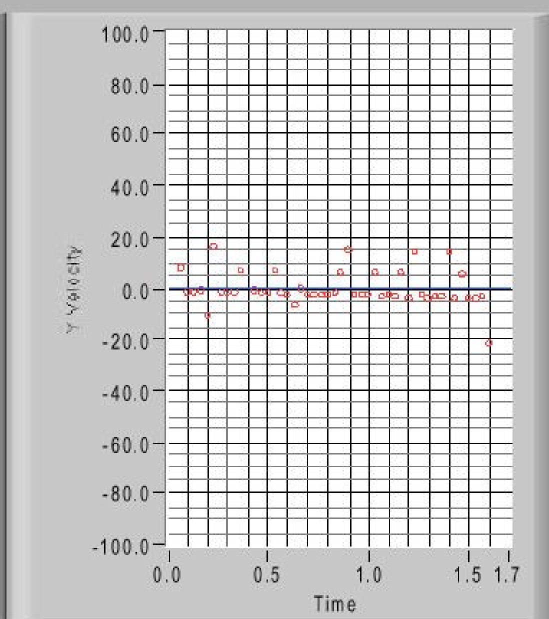
Y - Prediction Equation

u(t)=0.000 + 0.000t

Y - Fit Equation

u(t)=-2.000 + 0.000t





Vx - Prediction Equation

u(t)=31.000 + 40.000t

Vx - Fit Equation

u(t)=31.000 +40.000t

Vy - Prediction Equation

u(t)=0.000 + 0.000t

Vy - Fit Equation

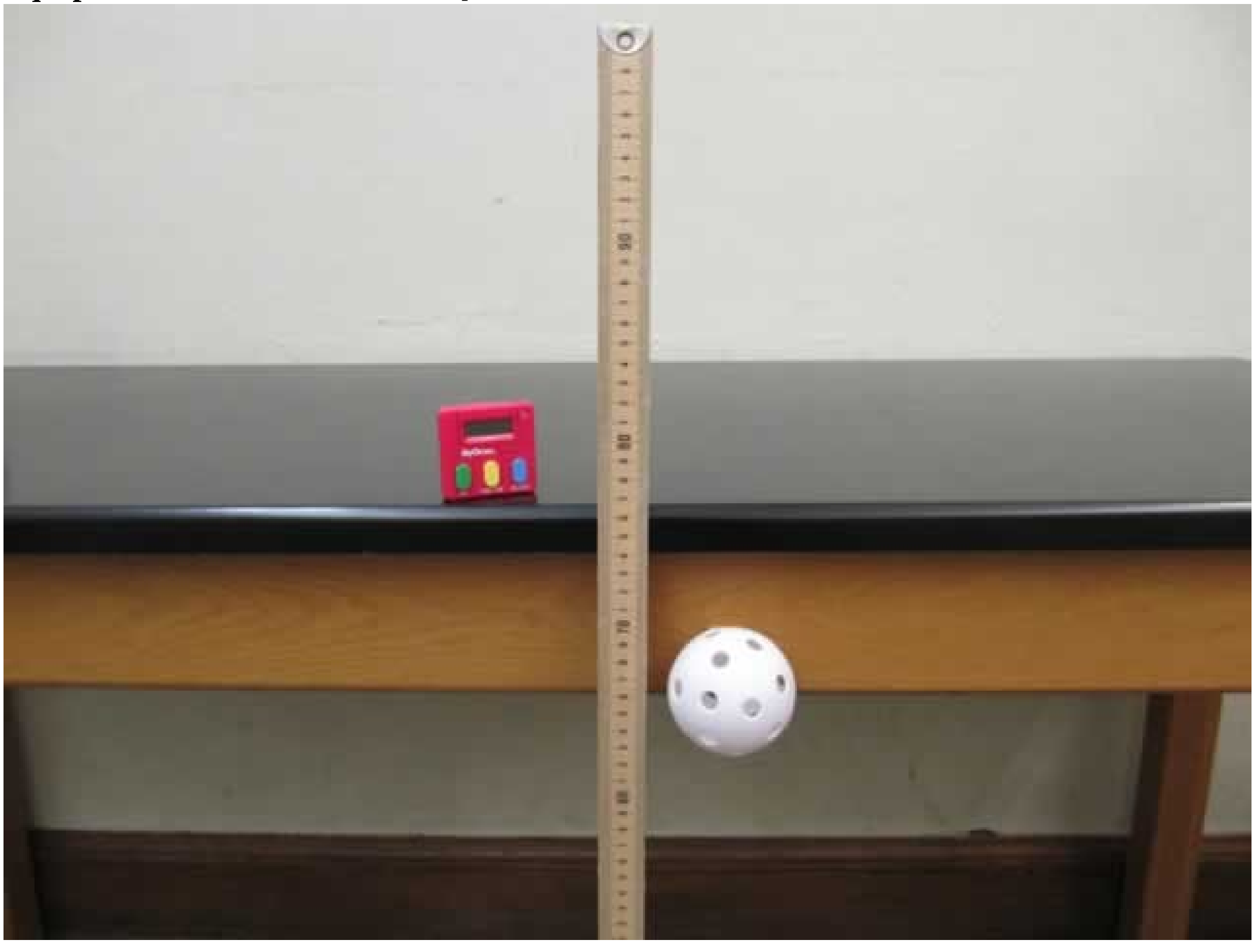
u(t)=0.000 + 0.000t

Lab 1 Problem 4: Mass and the Acceleration of a Falling Ball

Purposes:

1) To reinforce the distinction between velocity and acceleration, position and displacement, and average and instantaneous quantities.
2) To see these quantities and how they relate to constant acceleration.
3) To learn the importance of good data taking and analysis technique.
4) To witness the value of graphical representations of motion.
5) To analyze how air resistance affects the motion of freely-falling objects.

Equipment: ball set, meter stick, stopwatch



Teaching Tips:

1) It is possible that students will find a greater acceleration for the heavier balls. This is because of the air resistance. However, most students are struck by the close proximity of the accelerations. The different values may all be considered equivalent once you take uncertainty into account.
2) Ask students about the limiting values of mass and the gravitational acceleration of 9.8 m/s^2. Have them theoretically change the environment (a rock in water, a feather on the moon). You could also ask them if the mass of an object ever appears in the common kinematic equations.
3) Always give the students time to prove the answer to themselves. Seeing their own results is often the only way to break alternative conceptions.
4) Ask your students to be critical in choosing the balls with different masses. What makes for a significant change in mass?
5) Encourage your students to use the entire length of the spark record. Mass effects on the acceleration will be more noticeable at higher velocities.

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*.
7) The video camera's interlaced scan essentially breaks a frame up into two different frames (scanning every other line of a frame) 1/60 sec apart. When the object in free fall reaches a high enough speed, you can actually see both images on the screen. It is therefore important to use a consistent edge of the image to track the motion at time intervals of 1/30 sec.

Difficulties and Alternative Conceptions:

- Students believe that since something is heavier, it should fall faster. They know that the earth has a greater force on the heavier object. Save your explanation of forces until the next lab. Just let the students prove it to themselves that all masses fall at the same rate.

Predictions and Warm-up Questions:

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

Possible Discussion Questions:

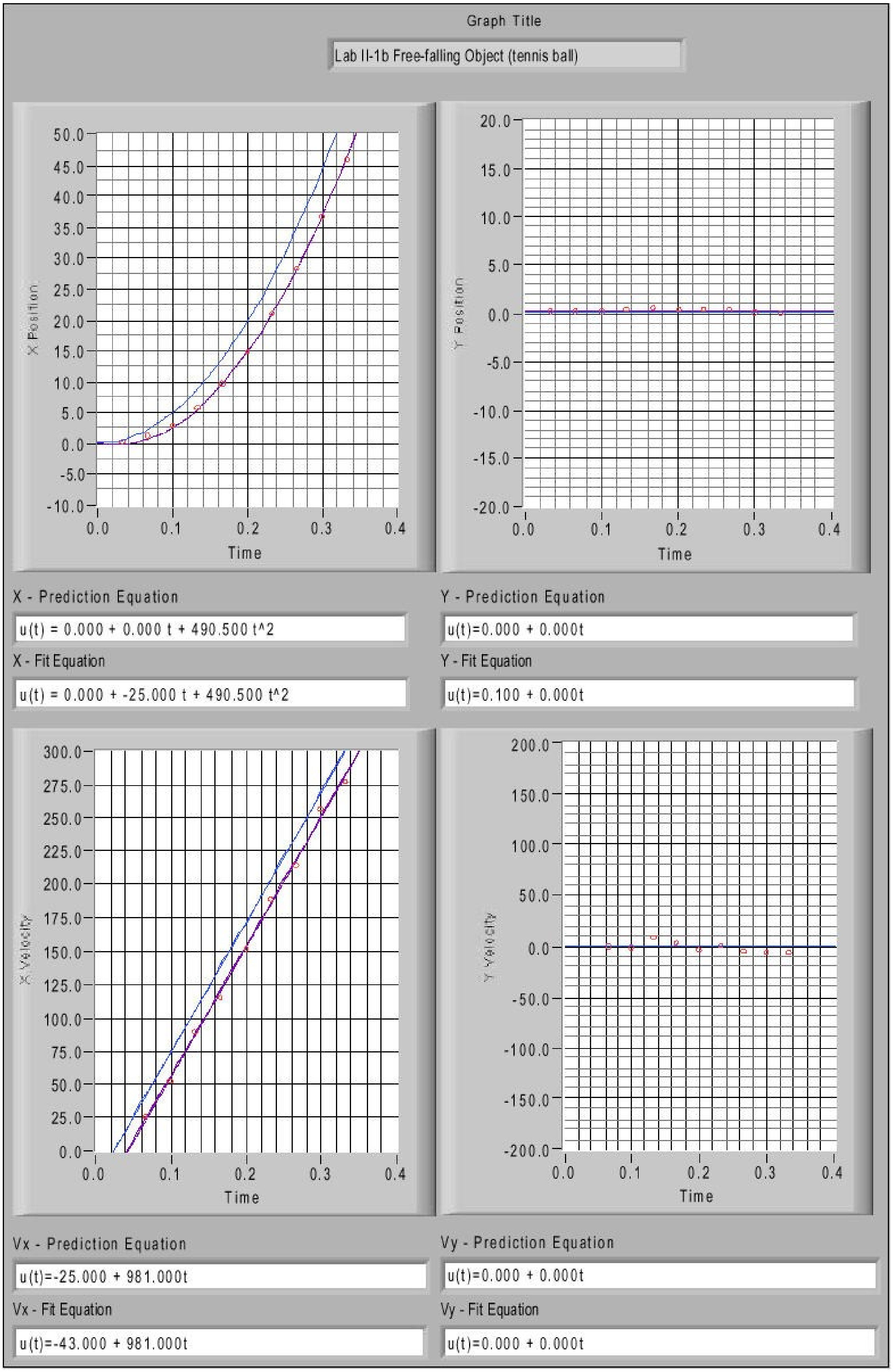
1) Considering the complexities of air resistance, is it possible for a skydiver to change her velocity and her acceleration as she falls?
2) Would a longer distance of fall give better data? Could you see the effects of air resistance with a longer fall?

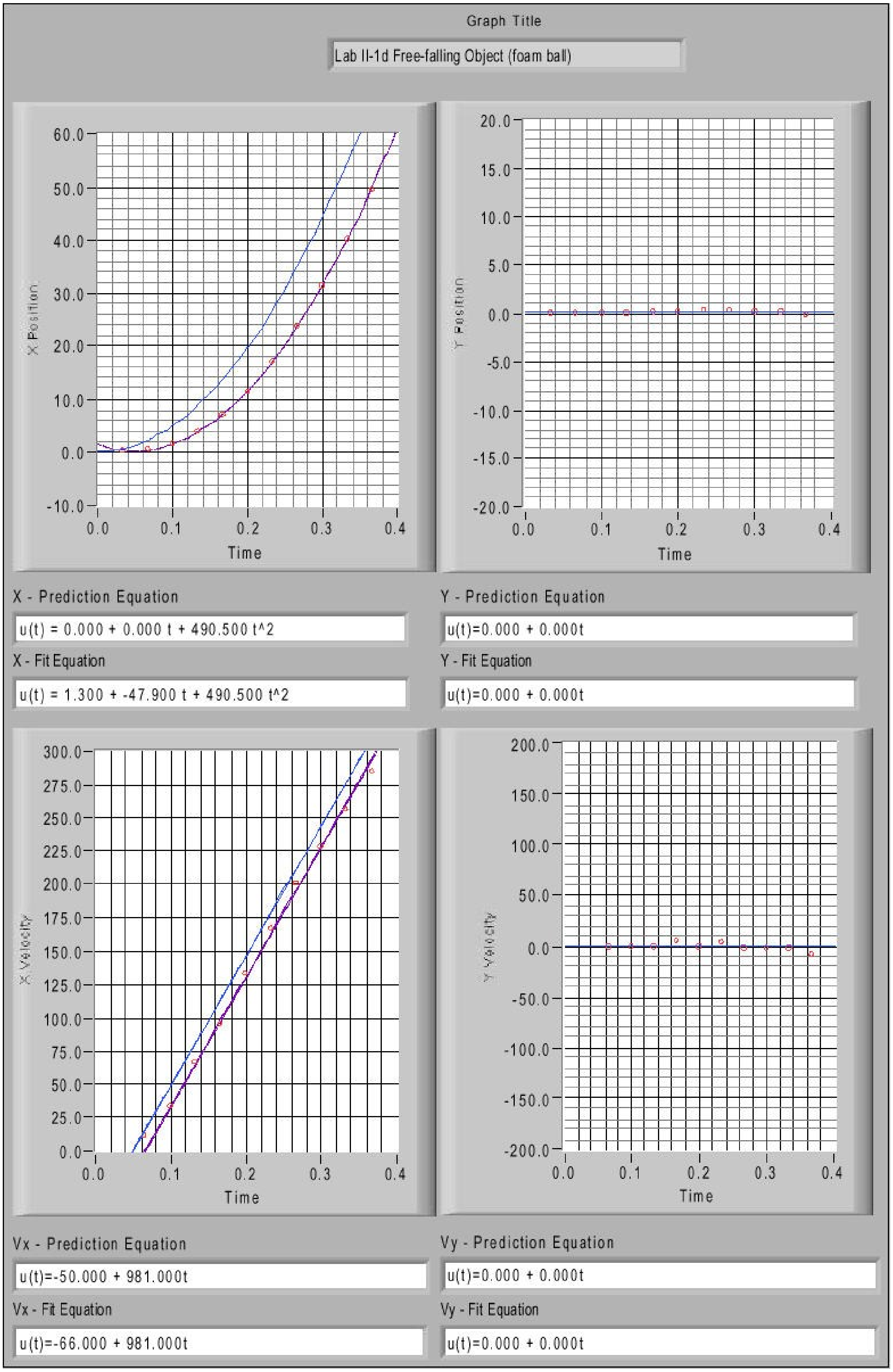
Sample Data:

baseball: mass = 144.50g, diameter = 7.40cm
tennis ball: mass = 60.00g, diameter = 6.71cm
rubber 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 $9.81 m/s^2$.

The following graphs are for the tennis ball and foam ball.


Graph Title
Lab II-1b Free-falling Object (tennis 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) = 0.000 + -25.000 t + 490.500 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.100 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-25.000 + 981.000t
Vx - Fit Equation
u(t)=-43.000 + 981.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


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

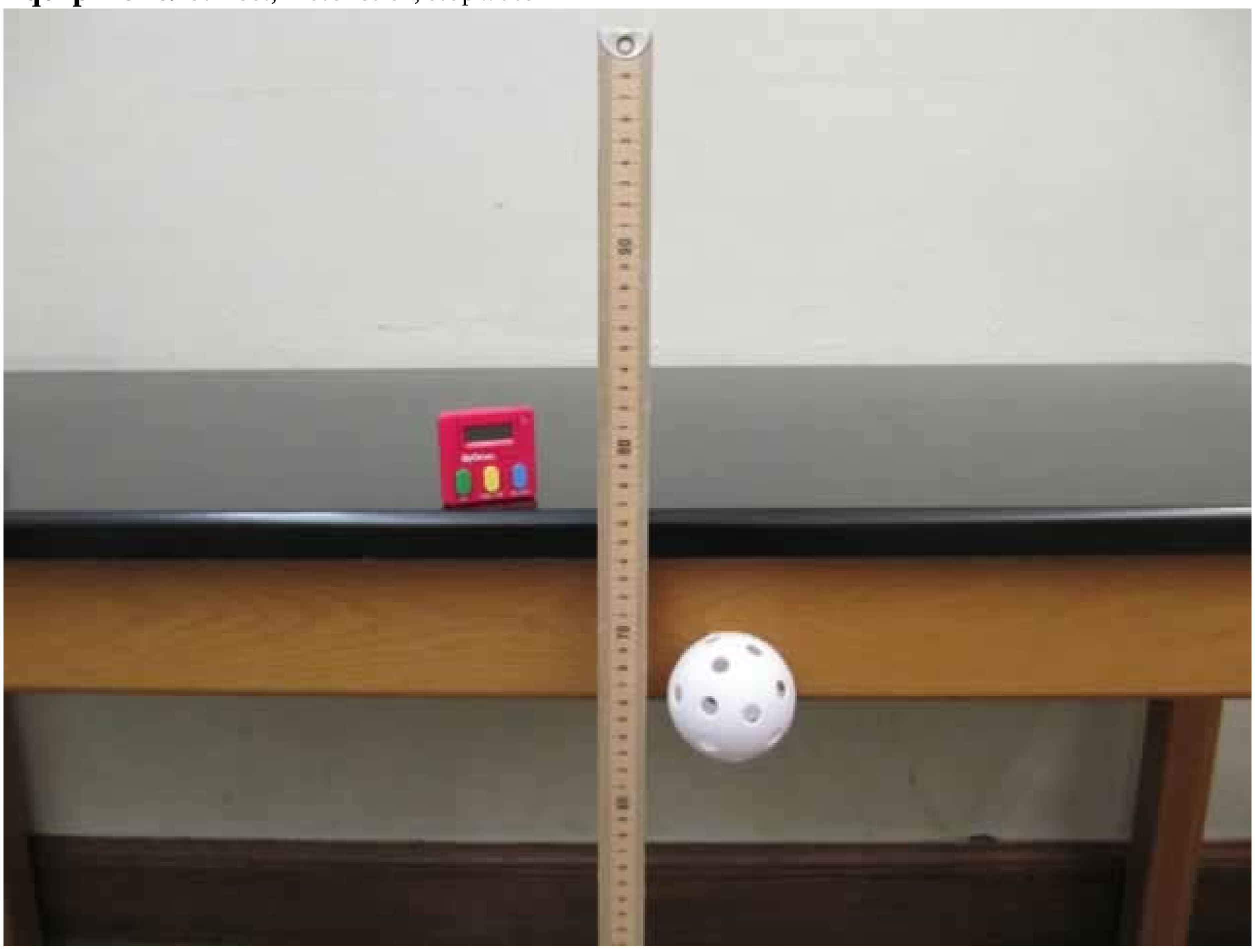
Lab 1 Problem #5: Laboratory Extension: Acceleration of a Ball with an Initial Velocity

This is a new lab, but it follows the same procedure as Problem #3: - Motion Down an Incline with an Initial Velocity. In fact, if the students already did that problem, all of the answers to Questions 1-4 should be the same. You can encourage them to move quickly through those questions in order to explore Questions 5-7, which have them manipulate functions to see the effect of initial velocity on instantaneous position vs. time graphs and instantaneous velocity vs. time graphs.

Purpose:

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

Equipment: ball set, meter stick, stopwatch



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. Once the ball is thrown too quickly, the students will not have enough data points to analyze their data accurately.
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 misconception 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.

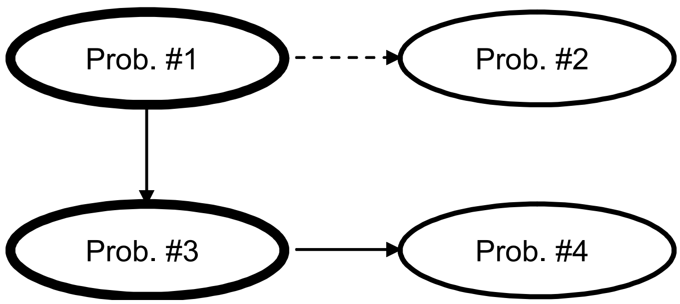
Extension Questions:

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

Laboratory 2: Description of Motion in Two-Dimensions

Laboratory 2 is a natural extension of lab 1. Students will continue to develop their understanding of position, velocity, and acceleration and how these quantities are related to time. Keep reminding your students of the differences between instantaneous and average quantities, because appreciating this difference will help students understand the uncertainties that appear when they calculate the acceleration of an object. Multi-dimensional motion is really a combination of independent one-dimensional motions. Build upon the ideas learned in the previous lab.

Problem 1 deals with motion up and down an incline. Problem 2 explores the acceleration of a cart and varying mass down an incline. Problem 3 introduces two-dimensional motion with classic projectile motion. Problem 4 ties the first two together by analyzing a projectile motion and its dependence upon mass.



Things to Remember:

1) Email labhelp@physics.umn.edu to report any problems with the equipment.
2) 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 lab students should be able to:

1) Determine how the mass of an object in free-fall affects the object's acceleration.
2) Describe how the horizontal and vertical components of the instantaneous velocity change when an object is in projectile motion.
3) Determine how the mass of a projectile affects its horizontal and vertical components of acceleration.

Things to check fifteen minutes before the lab:

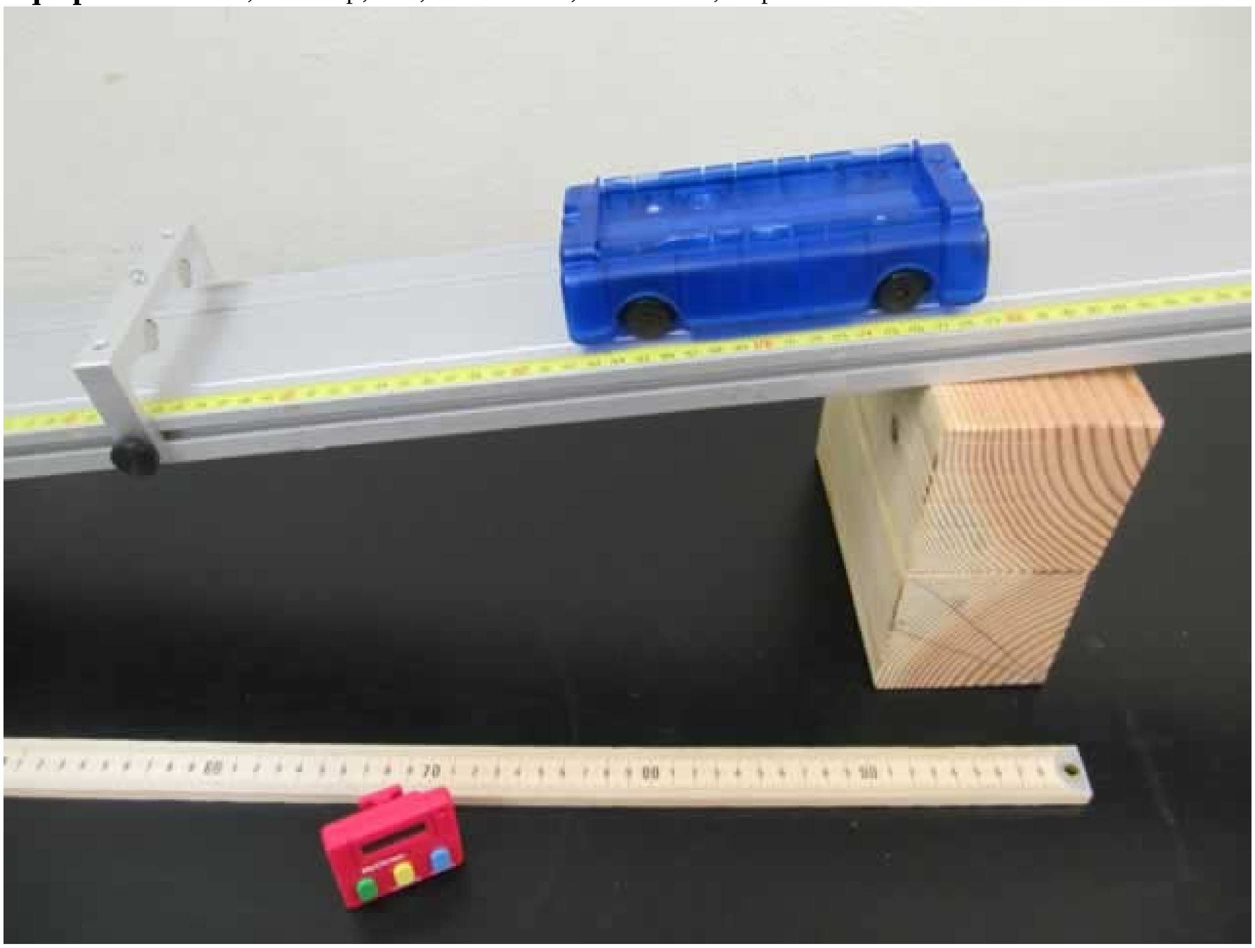
1) Find a friend and try out the labs concerning projectile motion; get an idea of how hard you can throw the various objects to get a good movie. This experience will allow you to help your students when they cannot get a good movie.
2) Make sure that you review how to change all of the adjustments of the camera so you can help a group who cannot get their camera to take a good movie.

Lab 2 Problem 1: Motion up and down an Incline

Purpose:

1) To show students that the acceleration up an incline is the same as the acceleration down an incline - same in magnitude *and* direction.

Equipment: track, end stop, cart, wood block, meter stick, stopwatch



Teaching Tips:

- Have the students compare the results of the motion of the cart up and down the incline. Watch for students who show that 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-versus-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 Alternative Conceptions:

- It is very common for students to think that acceleration is pointed up the incline, or that acceleration drops to zero when the velocity drops to zero. Beware of these misconceptions. Think of added experiments you can do to break them.

Prediction and Warm-up Questions:

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

Possible Discussion Questions:

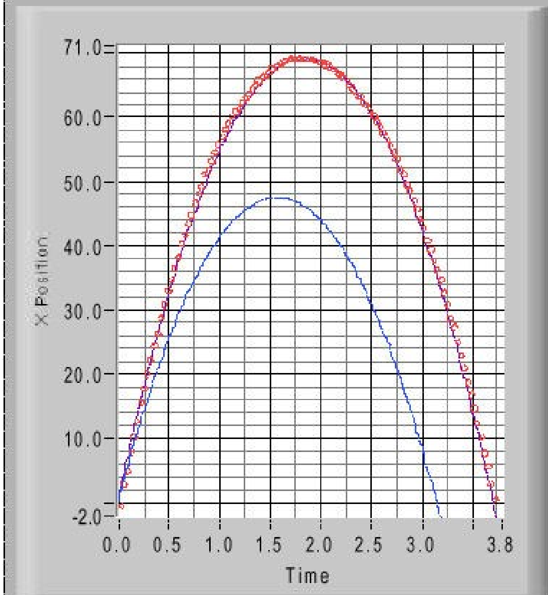
1) What is the direction of acceleration in this problem?
2) What does the term "deceleration" tell us about the relative directions of acceleration and velocity?
3) How does the videos compare between motion up an incline and motion down an incline?

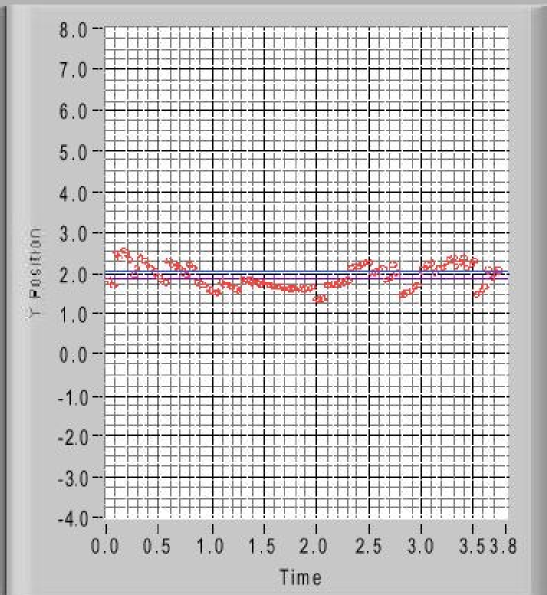
Sample Data:

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

Graph Title

Labl - 4 Motion Up and Down an Incline





X - Prediction Equation

u(t) = 0.000 + 60.000 t + -19.000 t^2

X - Fit Equation

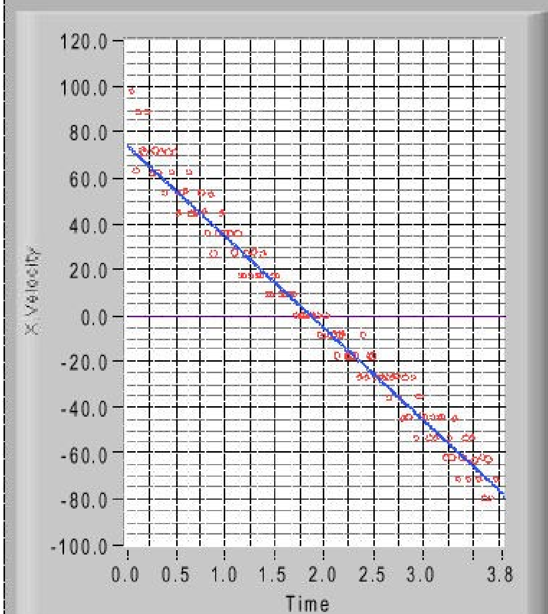
u(t) = 0.000 + 74.300 t + -20.000 t^2

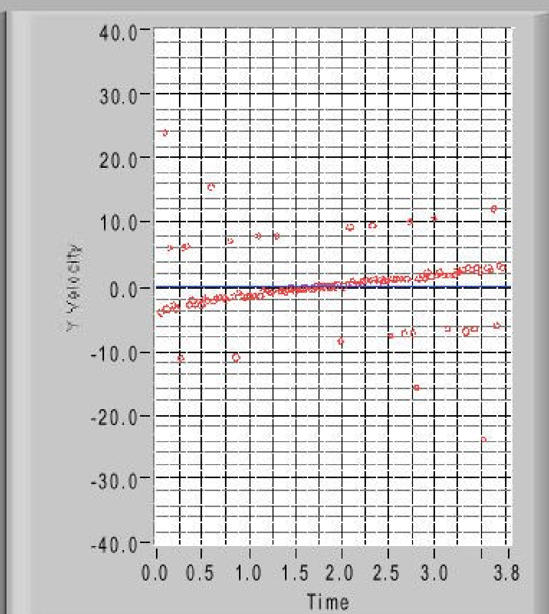
Y - Prediction Equation

u(t)=2.000 + 0.000t

Y - Fit Equation

u(t)=1.800 + 0.000t





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

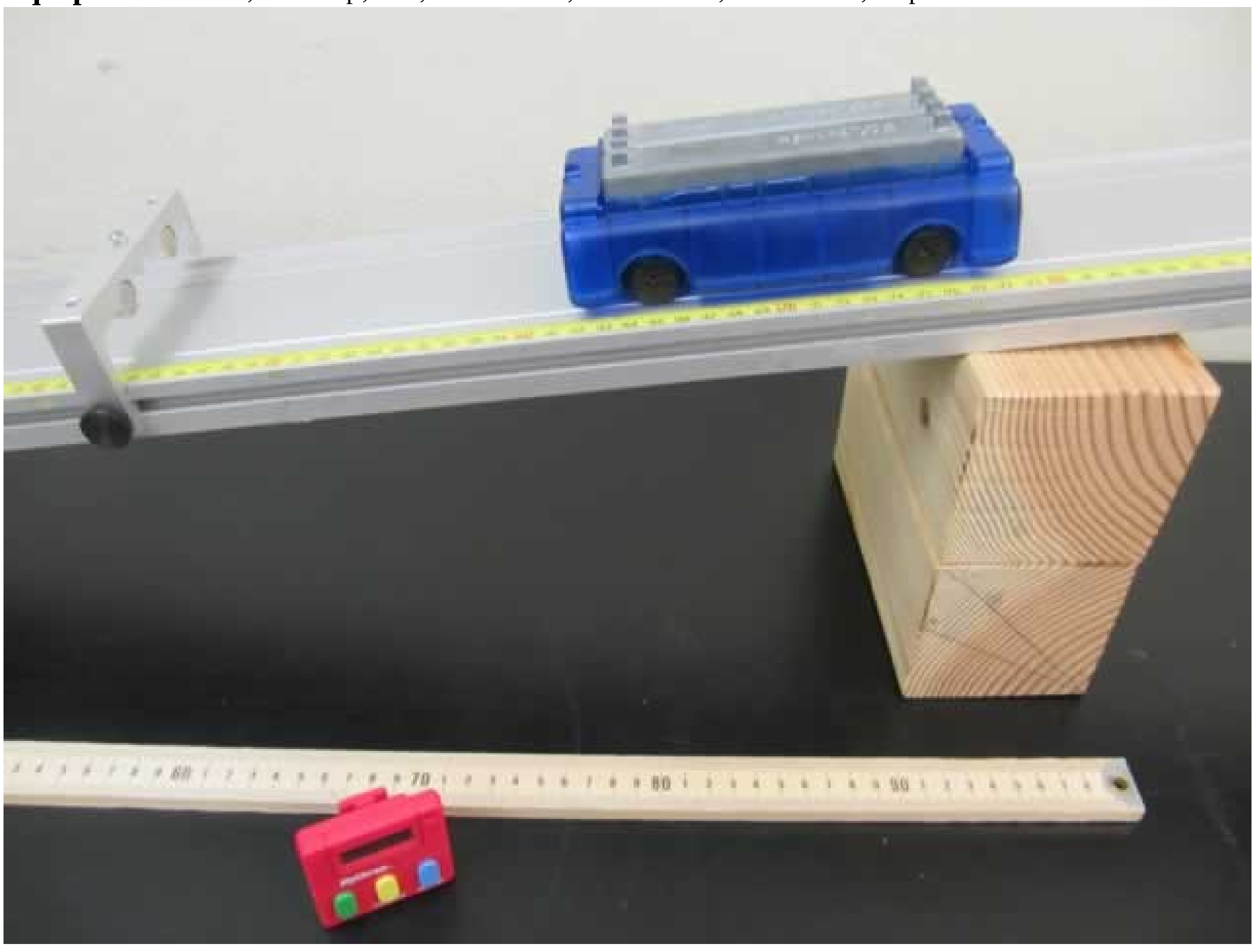
u(t)=0.000 + 0.000t

Lab 2 Problem 2: Mass and Motion Down an Incline

Purpose:

1) To convince students that acceleration down incline is independent of the mass of the cart.

Equipment: track, end stop, cart, cart masses, wood block, meter stick, stopwatch



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) If the students see a higher acceleration for heavier objects, you can raise the issue of air resistance (lighter objects feel more resistance if the two objects are of the same volume). However, you should first repeat the trial and test to see if the different accelerations are variable beyond uncertainty.
3) This is an interesting problem, but do not be concerned if students do not have time to reach it because the first problem of lab 2 deals with free-fall acceleration and variable masses.

Difficulties and Alternative Conceptions:

There is a very common misconception that heavier things accelerate faster than lighter things. Allow the students themselves to break this misconception with their own research. You must review the results with them and remind them what it means. You can point to the general kinematic equations and ask if they employ mass. However, try to avoid getting tangled in the mathematics. This is laboratory, and students should learn through hands-on discovery.

Predictions and Warm-up Questions:

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

Possible Discussion Questions:

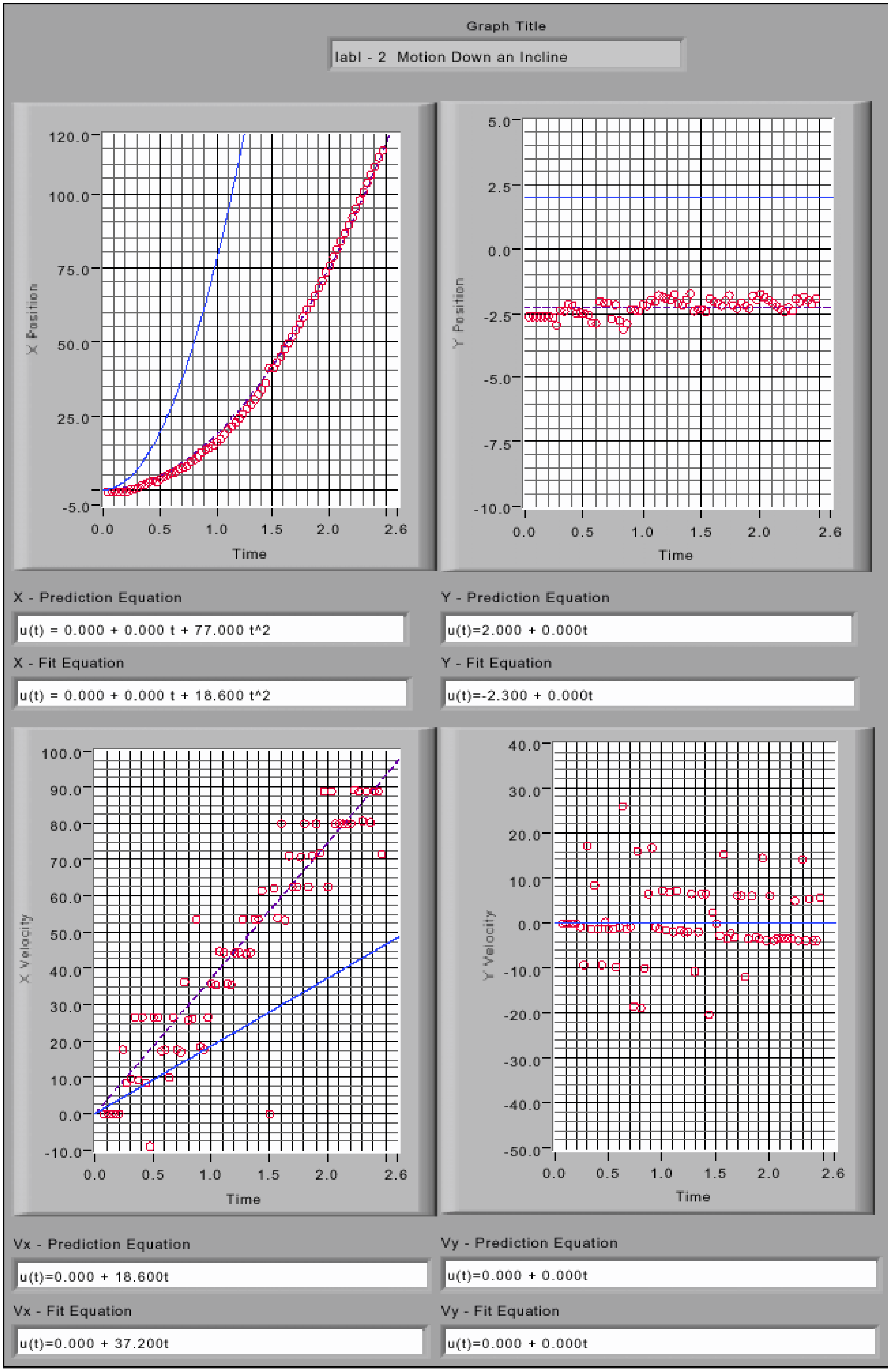
1) Will the acceleration be larger for a heavier car? Why?
2) When will the effects of air-resistance create significant error?

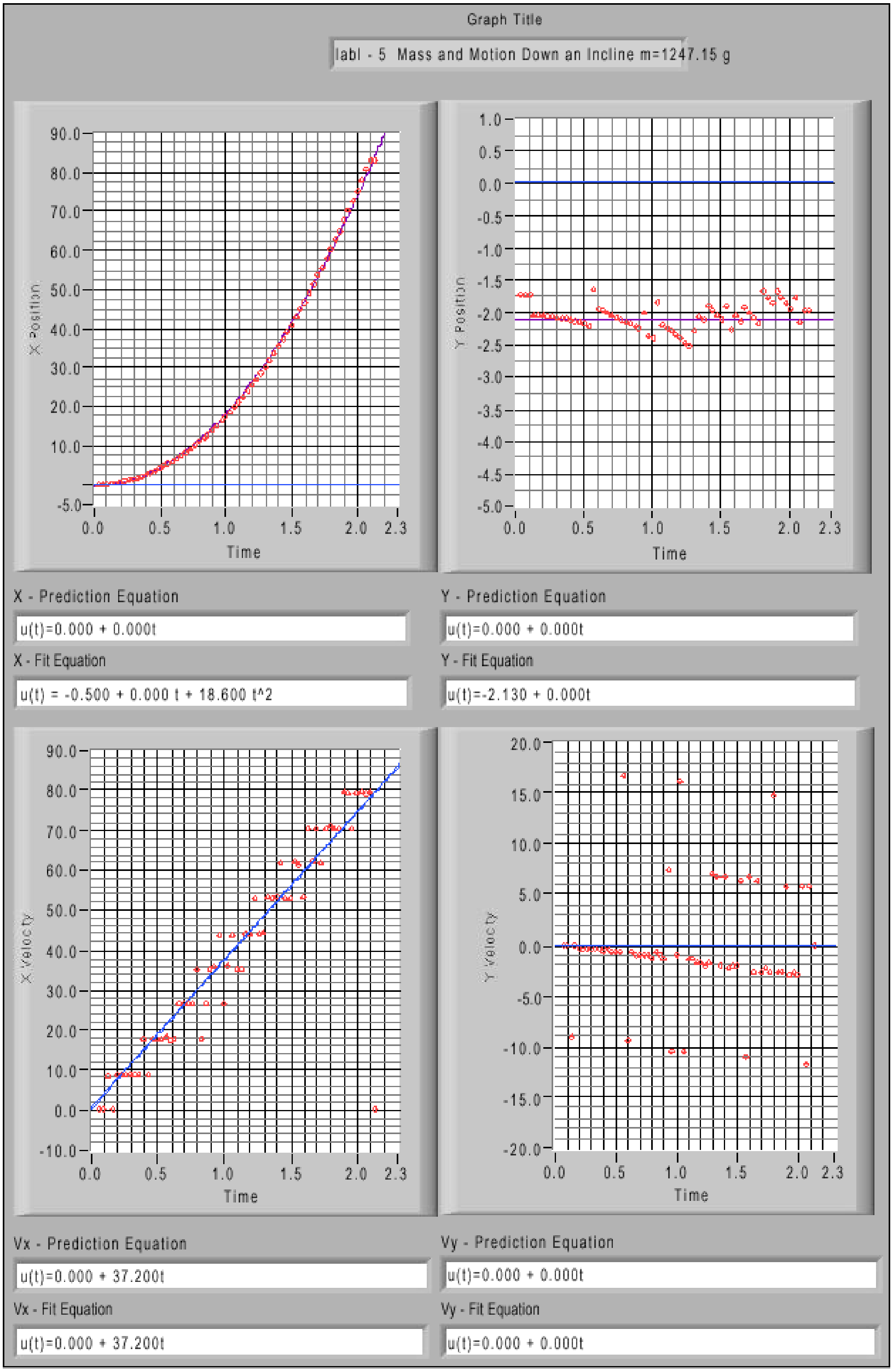
Sample Data:

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

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 - 2 Motion Down an Incline
X Position
Time
Y Position
Time
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
Time
Y Velocity
Time
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

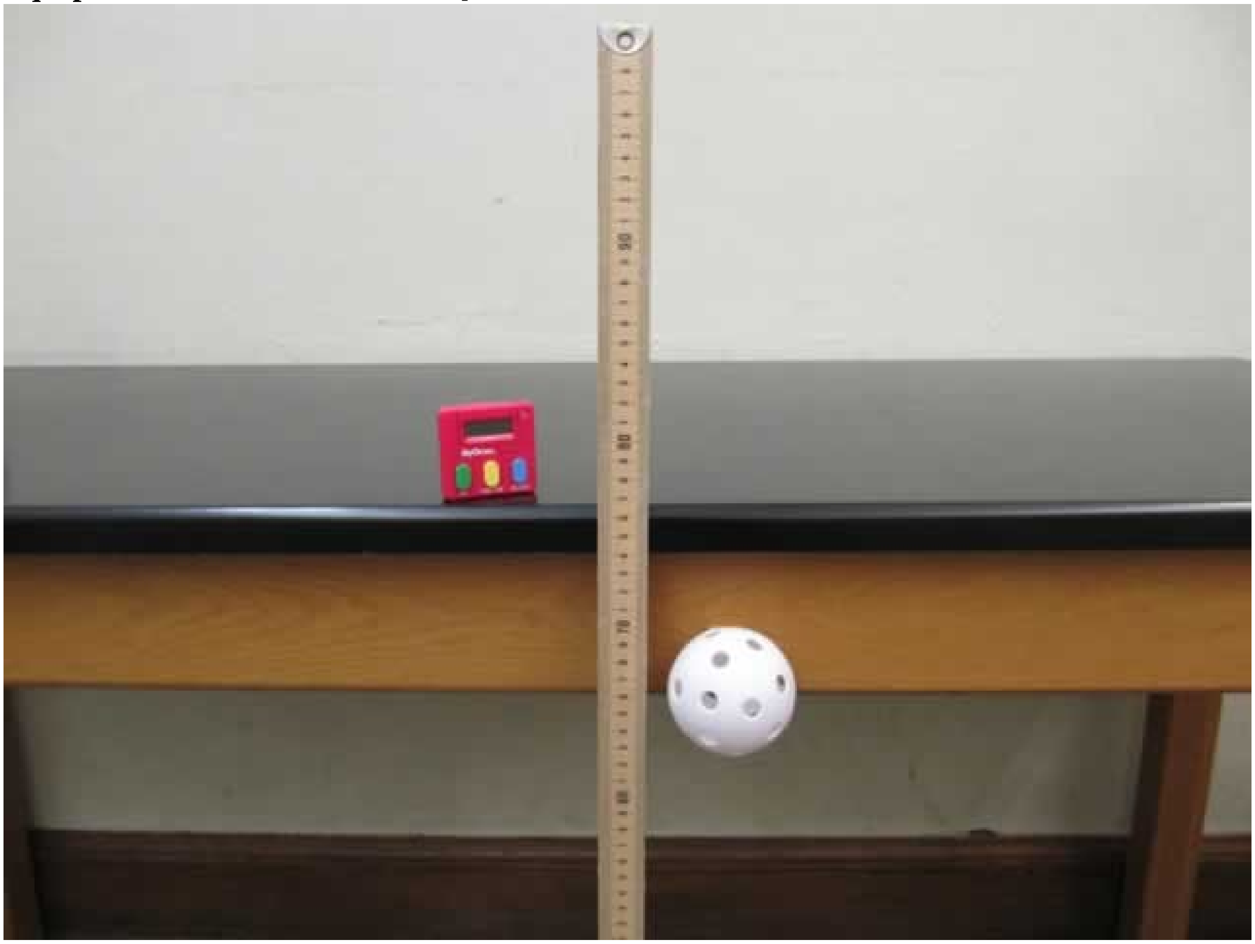

Graph Title
labl - 5 Mass and Motion Down an Incline m=1247.15 g
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t
X - Fit Equation
u(t) = -0.500 + 0.000 t + 18.600 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=-2.130 + 0.000t
X Velocity
Time
Y Velocity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

Lab 2 Problem 3: Projectile Motion and Velocity

Purpose:

- To demonstrate that two-dimensional motion can be analyzed as a combination of one-dimensional motions.

Equipment: ball set, meter stick, stopwatch



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) Stress vectors with this lab. Break the velocity into horizontal and vertical components and watch how the vectors change.
3) 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*. Watch out for students having trouble because of image splitting due to video interlacing.
4) 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 tend to confuse the mathematics behind two-dimensional motion. Stress that the horizontal and vertical motions can be analyzed independently.
- Students also have difficulty understanding that vertical motion can be negative. Look out for V-shaped velocity versus time graphs instead of graphs that extend straight below the axis as they should.

Prediction, Warm-up Questions:

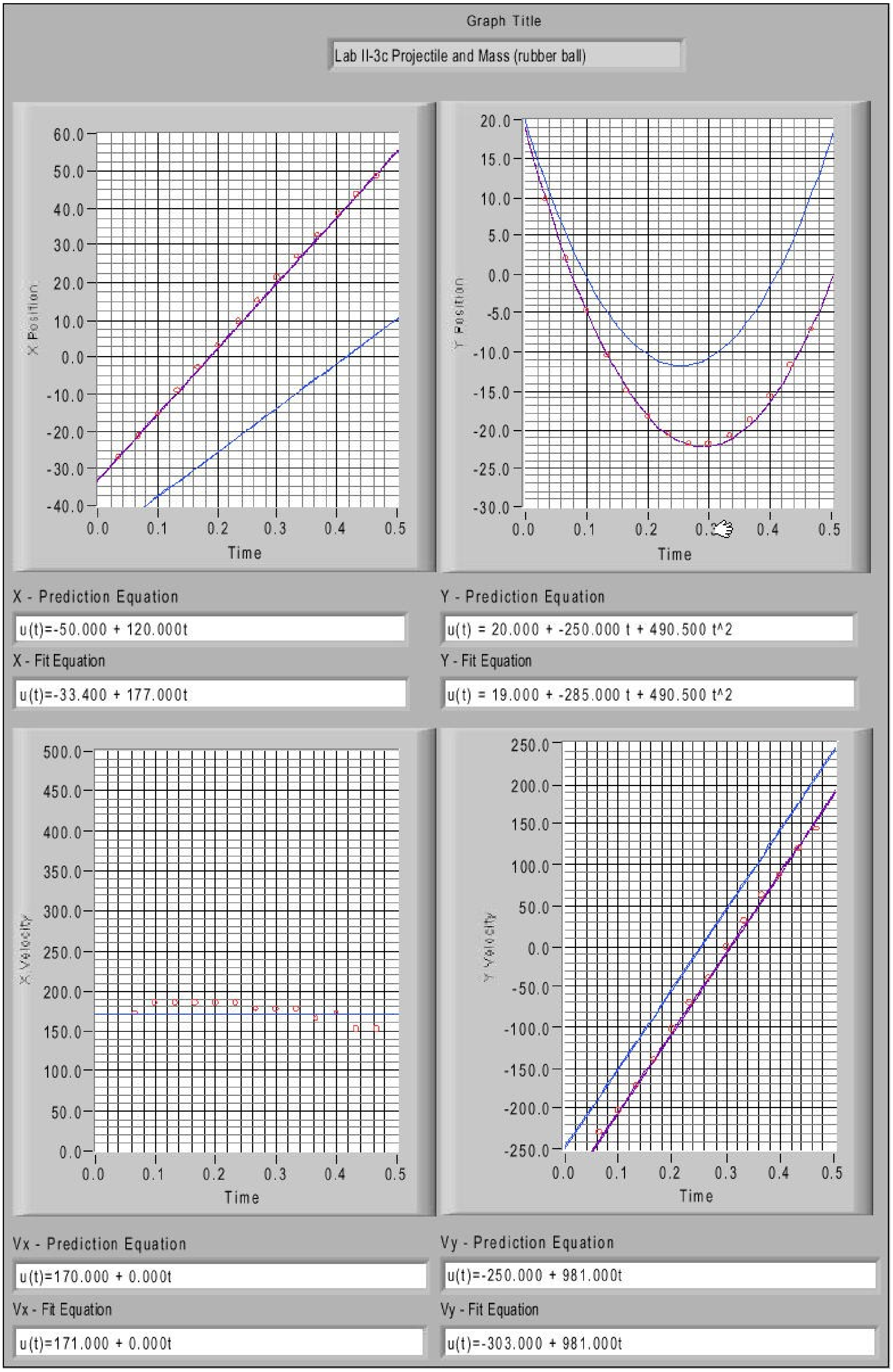
The prediction and Warm-up questions are straightforward and the prediction does not require any derived equation.

Possible Discussion Questions:

1) Is the vertical acceleration the same as the acceleration you found in problem 1?
2) Where in the path of trajectory is the *speed* the greatest? The least?

Sample Data:

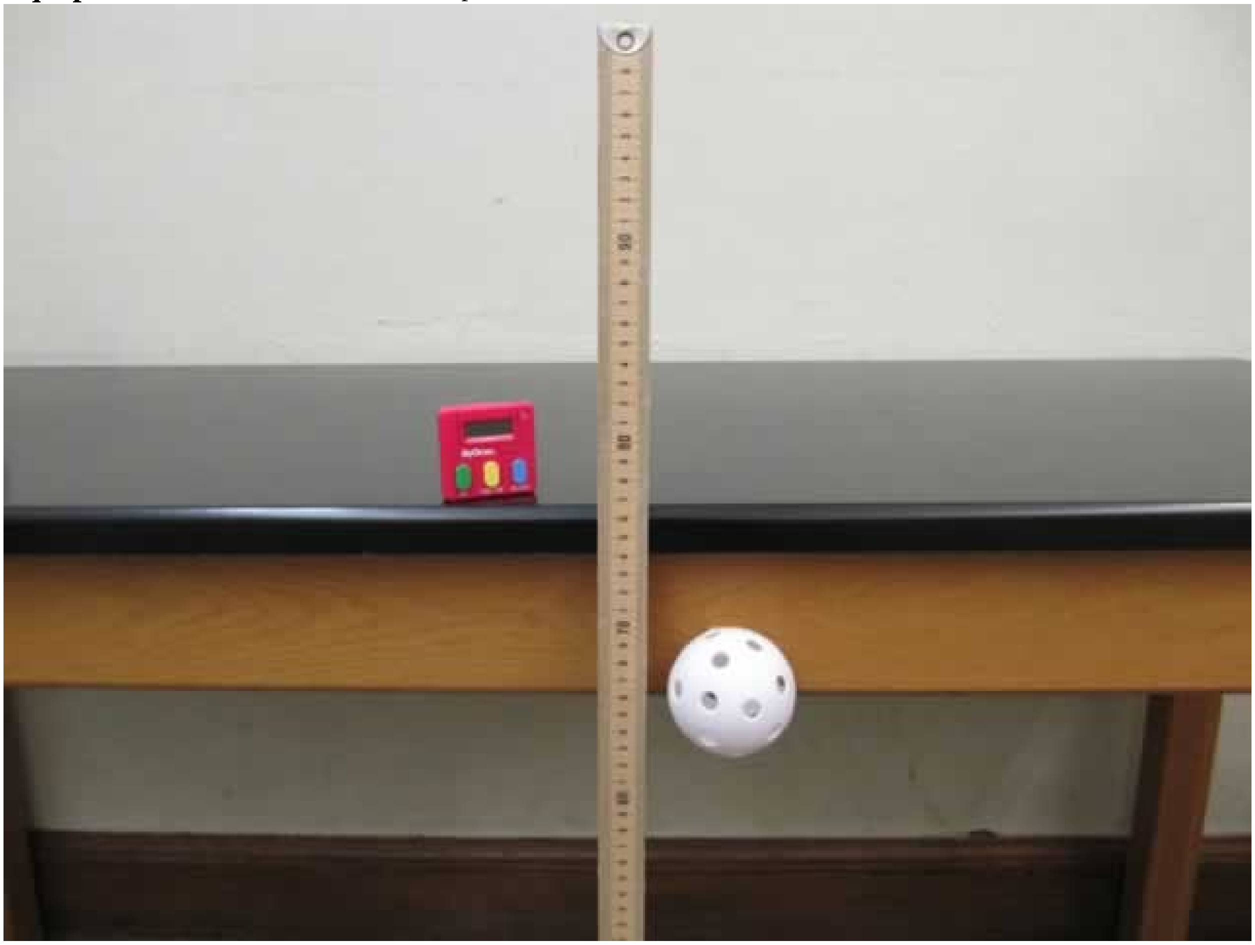
The motion along X (horizontal) axis is a constant velocity motion with velocity 177 cm/s, and the motion along Y (vertical) axis is a constant acceleration motion with acceleration 981 cm/s^2, with the defined positive directions for both axes.


Graph Title
Lab II-3c Projectile and Mass (rubber ball)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-50.000 + 120.000t
X - Fit Equation
u(t)=-33.400 + 177.000t
Y - Prediction Equation
u(t) = 20.000 + -250.000 t + 490.500 t^2
Y - Fit Equation
u(t) = 19.000 + -285.000 t + 490.500 t^2
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=170.000 + 0.000t
Vx - Fit Equation
u(t)=171.000 + 0.000t
Vy - Prediction Equation
u(t)=-250.000 + 981.000t
Vy - Fit Equation
u(t)=-303.000 + 981.000t

Lab 2 Problem 4: Projectile Motion and Mass

Purpose: To show that the vertical acceleration of a projectile is independent of the projectile's mass.

Equipment: ball set, meter stick, stopwatch



Teaching Tips:

- As the groups go through problem 3, give each group a ball with different mass for the projectile. With multiple analyses in problem 3, you can pool the class's results and have data for problem 4.

Predictions and Warm-up Questions:

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

Possible Discussion Questions:

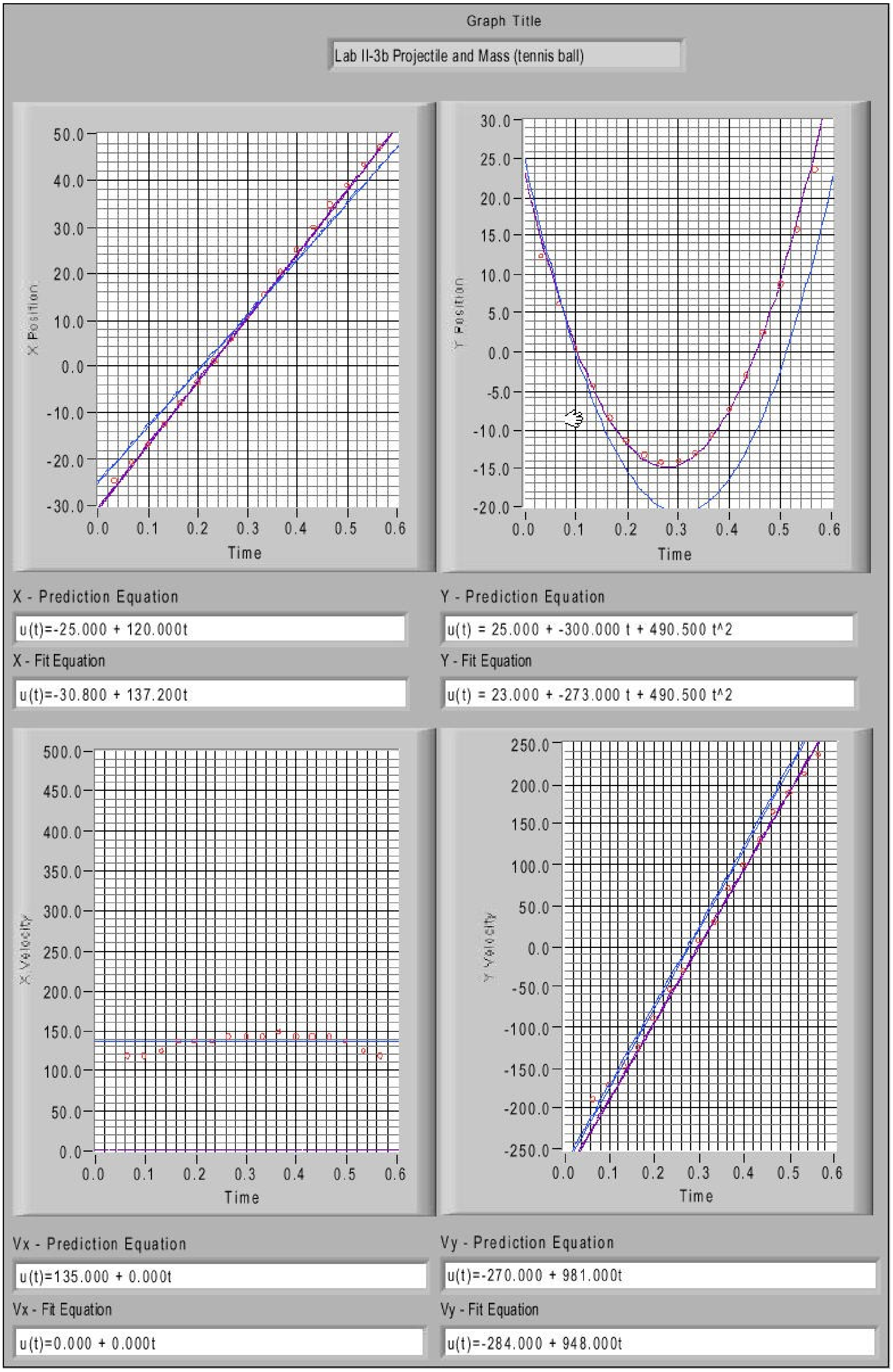
- If vertical acceleration does not change with mass, why can you hit a baseball much further than you can hit a bowling ball? (This questions will prime your class to think about forces)

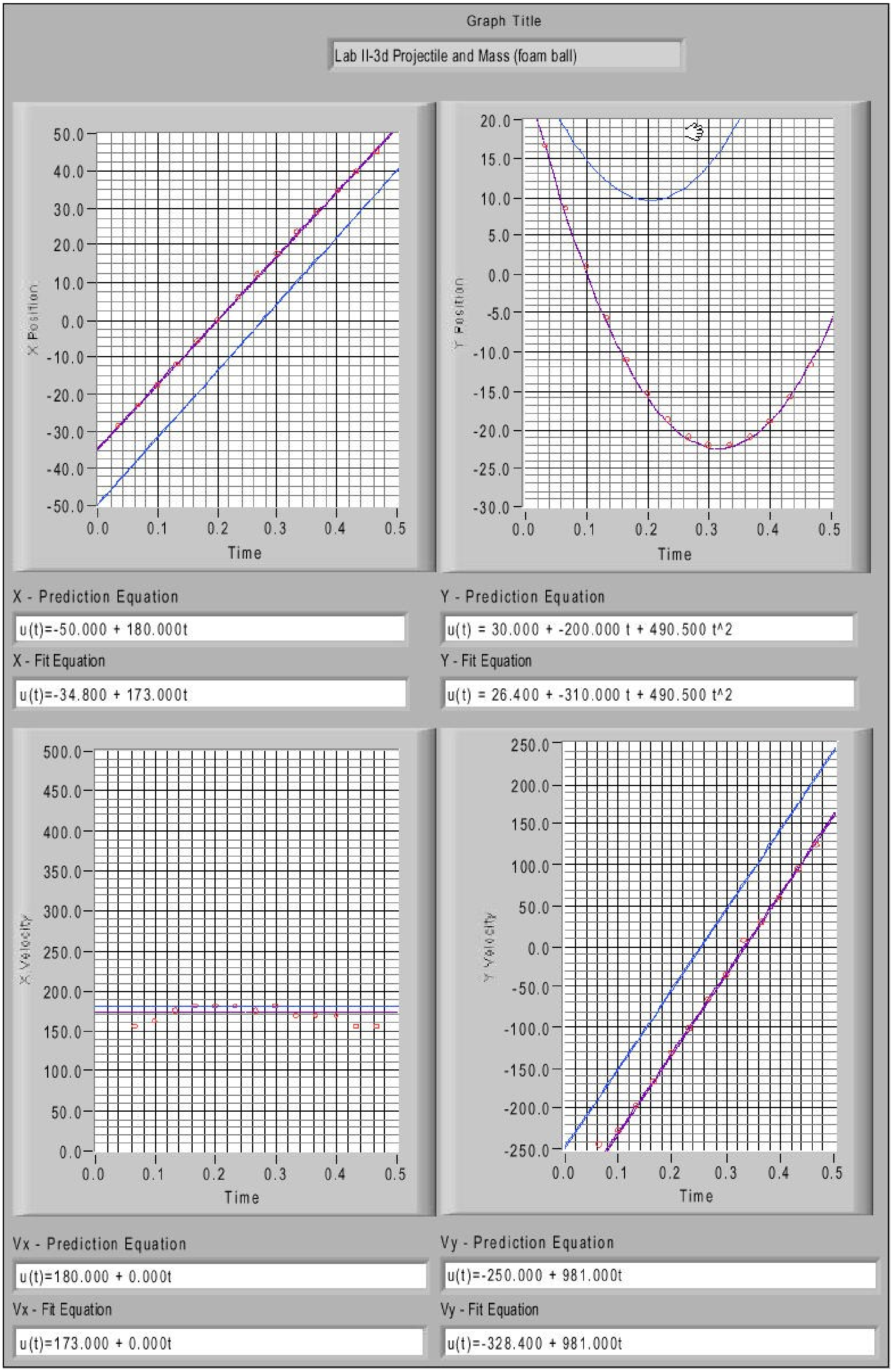
Sample Data:

The data for Problem 2 can be used as the data for the first trial of this problem.
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 projectiles of all four balls (with different masses) show a constant velocity motion along horizontal (X) direction, and a constant acceleration motion, with acceleration $9.81 m/s^2$, along vertical (Y) direction.

Graphs are included for the tennis ball and foam ball:

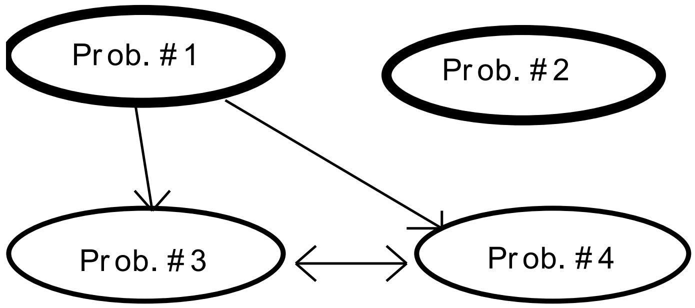



Graph Title
Lab II-3d Projectile and Mass (foam ball)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=-50.000 + 180.000t
X - Fit Equation
u(t)=-34.800 + 173.000t
Y - Prediction Equation
u(t) = 30.000 + -200.000 t + 490.500 t^2
Y - Fit Equation
u(t) = 26.400 + -310.000 t + 490.500 t^2
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=180.000 + 0.000t
Vx - Fit Equation
u(t)=173.000 + 0.000t
Vy - Prediction Equation
u(t)=-250.000 + 981.000t
Vy - Fit Equation
u(t)=-328.400 + 981.000t

Laboratory 3: Forces

Laboratory 3 introduces the physical description of forces. Friction, tension in strings, and the normal forces are all examples of contact forces. Students have witnessed gravitational field forces in action with the falling bodies, and they will study more field forces later in the course.

As a teacher, emphasize the importance of a force diagram and writing down Newton's Second Law. Students often see physics as a collection of random situations and equations. You need to show them a strategic approach that they can use to solve any problem (i.e. force diagrams and $F_{net} = ma$).



General Teaching Tips:

1) Warn your students that the predictions become more intricate and mathematical in this lab. Keep your expectations high regarding their journals and preparatory work.
2) If the class is having trouble, go through the prediction very slow. If your speed feels excruciatingly slow to you, it is still too fast for most students.
3) Problems 3 and 4 are very similar. Avoid having a group do both problems.
4) Remind them that the normal force is always perpendicular.
5) Show students why the normal force and the weight are *not* third law pairs.
6) Do all that you can to keep the environment consistent.
7) Remind your skeptical students that the sliding carts and blocks are models of other systems. We are looking at the models in lab not to understand the models themselves, but to understand the more general ideas, then to apply those ideas to more practical situations.

Things to Remember:

1) Send an email to labhelp@physics.umn.edu to report all equipment problems.
2) 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:

1) Make qualitative predictions about forces in genuine systems, and test those predictions.
2) Analyze forces as vectors. Decompose force vectors when necessary.
3) Describe the characteristics of the friction force.
4) Employ the problem-solving strategy to classic physical situations.

Things to check fifteen minutes before lab:

1) Learn how to use the computer software applications - VideoRECORDER and Motionlab.
2) Know how to obtain consistent results with the sliding wood/ cloth block (i.e. to prevent sticking as the block slides down the board).
3) Know how to secure the incline at various reasonable angles for problems 3&4.

Lab 3 Problem 1: How Surfaces Affect the Kinetic Frictional Force

Purposes:

1) To introduce a physical understanding of friction.
2) To show that the tension in the rope is not equal to the weight of the hanging mass.

Equipment: track, end-of-track pulley, cloth block, mass hanger, mass set, string, masking tape

Teaching Tips:

1) This problem asks for the frictional force. It is meant to show students that there is another force acting on the sliding block other then the tension in the string.
2) Make sure the hanging mass is large enough to overcome the stickiness between the board and the block. You must see a smooth acceleration, and you may wish to use the sandboxes to catch the hanging masses.
3) Understanding force diagrams is essential. Spend time showing students how the two force diagrams are connected.
4) Tell your students to be as careful as possible. However, you should remind them that many errors come into play, and that frictional forces may be different for each group.
5) The video should be taken for the whole set up of the experiment in order to avoid taking the data after the mass A hit the ground.
6) Keep the aluminum track clean; even your hands carry oils that can hinder the smooth motion of the block.
7) You may want to explain why friction is not a conservative force. (There is no associated potential energy, and the direction of frictional forces can change.)

Difficulties and Alternative Conceptions:

- Students have difficulty connecting the two force diagrams. Remind them that the pulley (assumed frictionless) translates the vertical weight of the hanging masses into a horizontal pull on the block.

Prediction and Warm-up Questions:

The smallest coefficient of friction is aluminum on aluminum; then comes the wood on aluminum; and the largest coefficient of friction is wood on wood. (Assuming typical weather conditions and clean alumnium.)

The force on each object is:

$$mg - T = ma$$
$$T - f_k = Ma$$

Eliminating T yields

$$f_k = m(g - a) - Ma$$

where m is the hanging masses, M is the mass of the block, and a is the acceleration of the system.

Possible Discussion Questions:

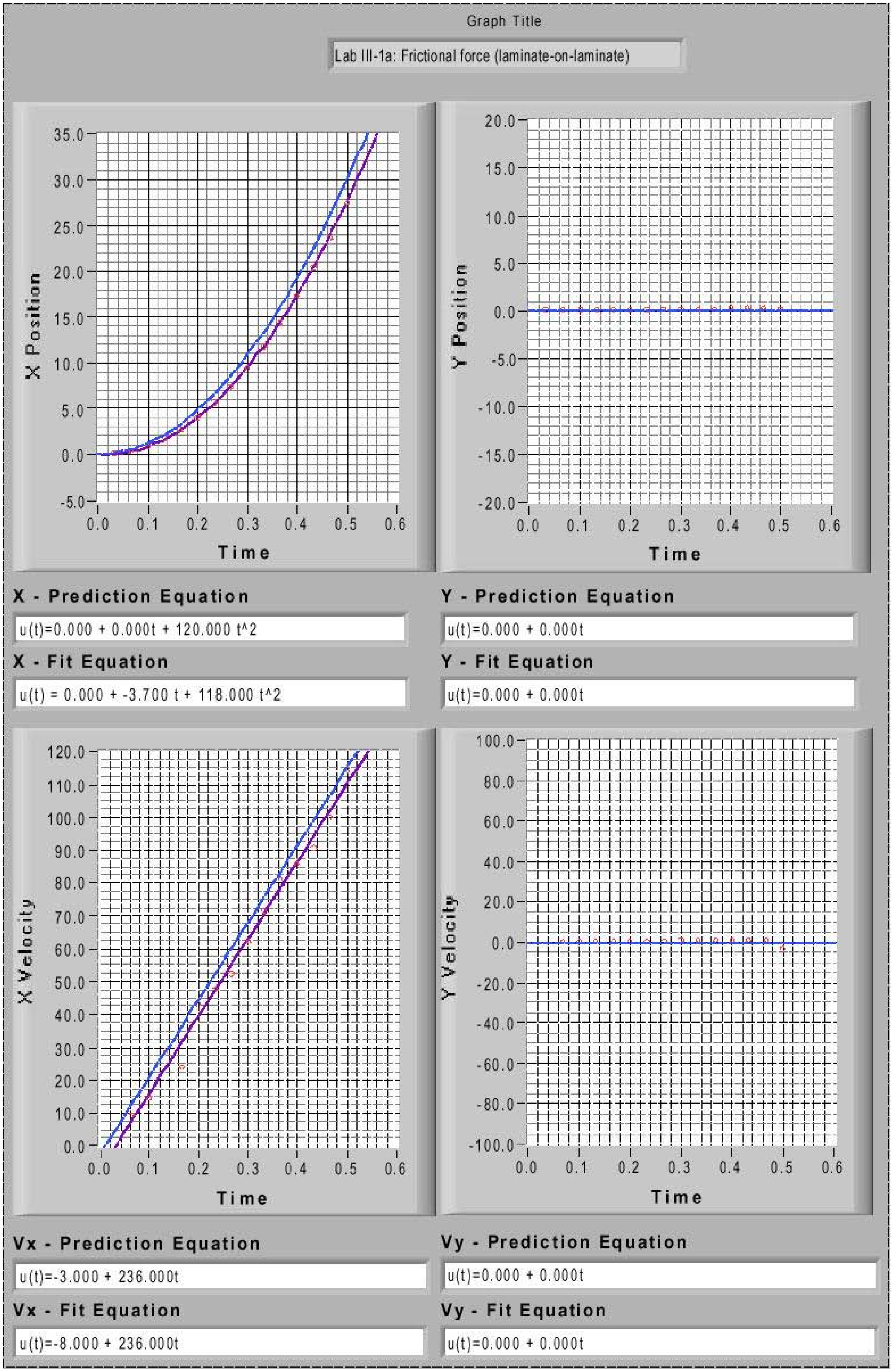
1) If there were no friction, would the system accelerate at 9.8 m/ s^2? Why or why not?
2) Why do some groups obtain a higher / lower value of friction than others?
3) How does the normal force affect the force of friction?
4) What is the frictional force? Is if the microscopic nature of the material? Is it the electrostatic interaction between materials?

Sample Data:

(Note: This data was taken using a sliding disk on laminate from a previous version of the problem, not the wood/ cloth block on an aluminum track)

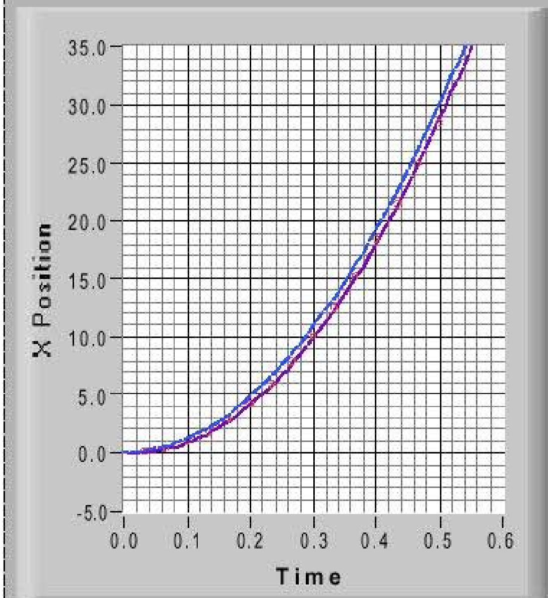
Mass of the hanging mass: m = 100g; mass of the disk: M = 137.53g

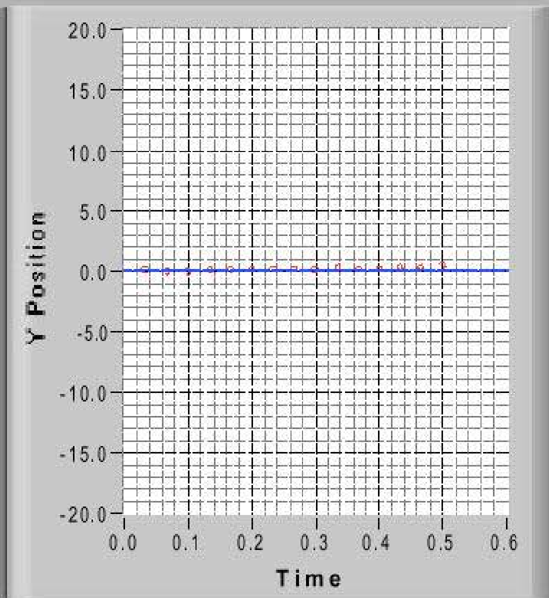
Surfaces	Acceleration a (cm/ s^2)	Friction f_k (10^4 g.cm^2/ s^2)	Coefficients of Friction μ_k
laminate-on-laminate	236.00	4.204	0.312
composition -on-laminate	246.40	3.957	0.293
composition -on comp.	222.00	4.537	0.336


Graph Title
Lab III-1a: Frictional force (laminate-on-laminate)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 120.000 t^2
X - Fit Equation
u(t) = 0.000 + -3.700 t + 118.000 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)=-3.000 + 236.000t
Vx - Fit Equation
u(t)=-8.000 + 236.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

Graph Title

Lab III-1b: Frictional force (board-on-laminate)





X - Prediction Equation

u(t)=0.000 + 0.000t + 120.000 t^2

X - Fit Equation

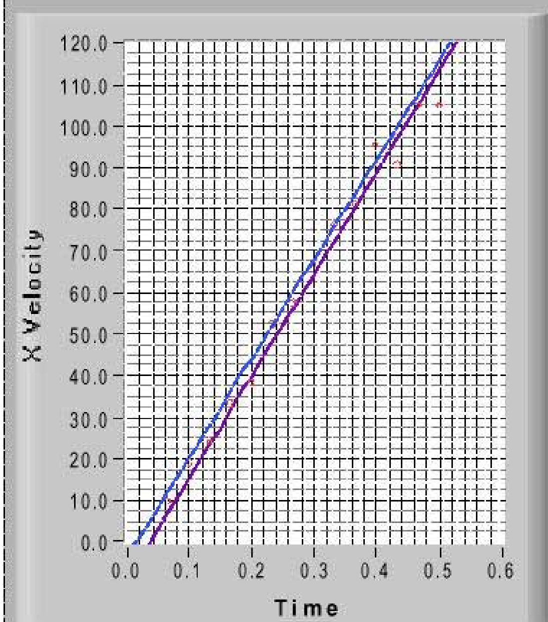
u(t) = 0.000 + -4.300 t + 123.200 t^2

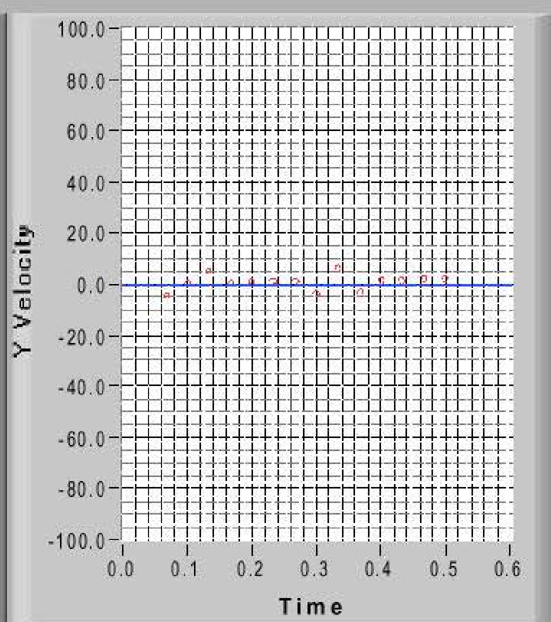
Y - Prediction Equation

u(t)=0.000 + 0.000t

Y - Fit Equation

u(t)=0.000 + 0.000t





Vx - Prediction Equation

u(t)=-4.300 + 240.000t

Vx - Fit Equation

u(t)=-9.800 + 246.400t

Vy - Prediction Equation

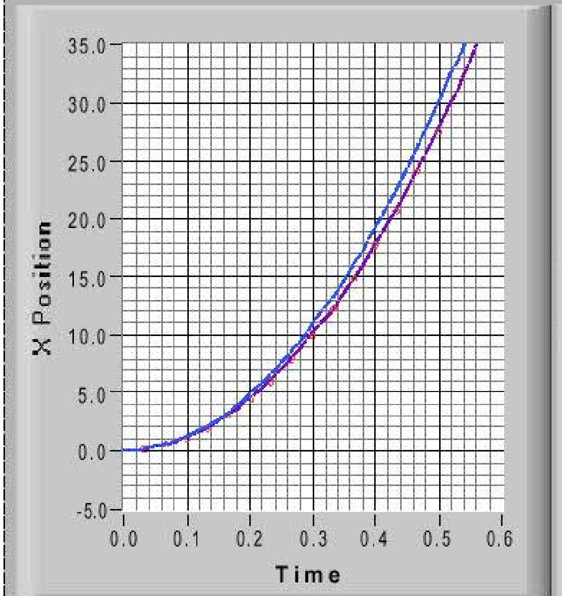
u(t)=0.000 + 0.000t

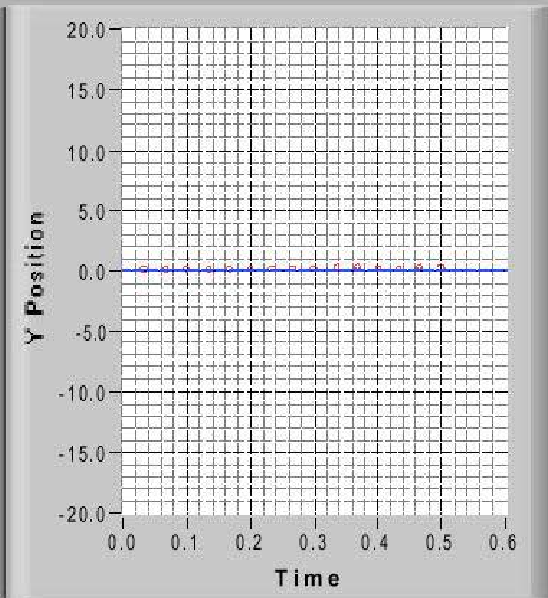
Vy - Fit Equation

u(t)=0.000 + 0.000t

Graph Title

Lab III-1c: Frictional force (board-on-board)





X - Prediction Equation

u(t)=0.000 + 0.000t + 120.000 t^2

X - Fit Equation

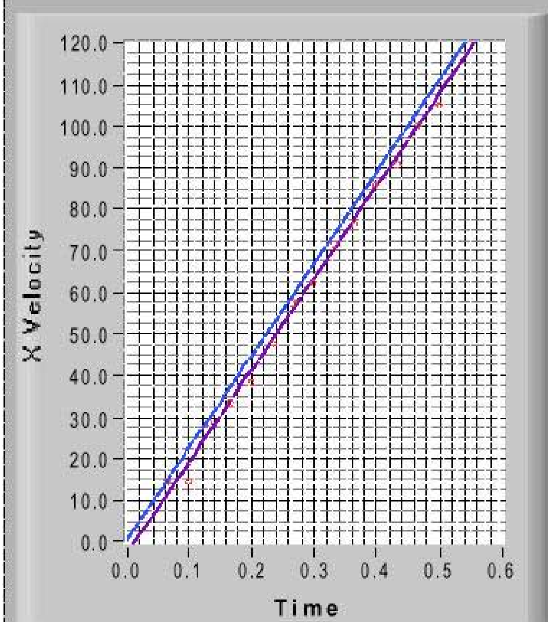
u(t) = 0.000 + 0.000 t + 111.000 t^2

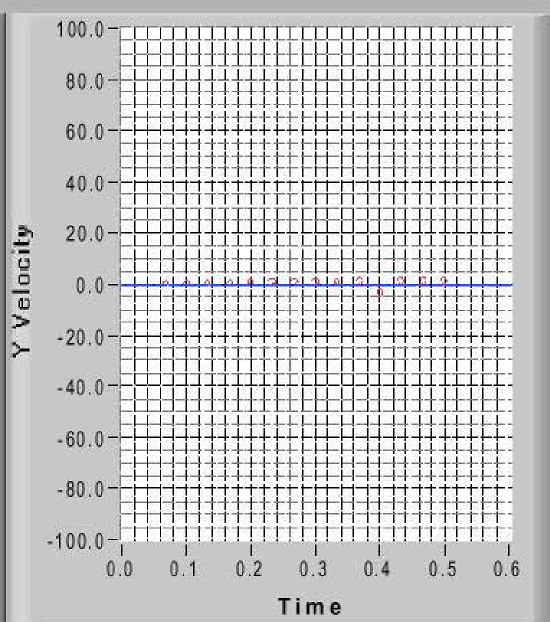
Y - Prediction Equation

u(t)=0.000 + 0.000t

Y - Fit Equation

u(t)=0.000 + 0.000t





Vx - Prediction Equation

u(t)=0.000 + 222.000t

Vx - Fit Equation

u(t)=-3.400 + 222.000t

Vy - Prediction Equation

u(t)=0.000 + 0.000t

Vy - Fit Equation

u(t)=0.000 + 0.000t

Lab 3 Problem 2: Forces in Equilibrium

Purposes:

1) *This is a favorite problem* because it shows how to use Newton's Second Law to analyze a complex situation. It combines geometry with algebra and physics to arrive at a sensible prediction regarding the behavior of a natural system.
2) To show students that the concept of force is useful even in static situations.

Equipment: pulleys, table clamps, 3 mass sets, string & meter stick

Teaching Tips:

1) Show your students how to find the error of each measurement by displacing the central masses and testing to see if they return to the same position.
2) Students will see that the error increases with increasing mass. This is because the pulleys (assumed frictionless) actually have a lot of friction when the mass increases.
3) Make sure each group can find 5-6 data points. They may have to bring the pulleys closer together, or increase the masses of objects A and C.
4) Warn your students that the algebra is messy. We grow up thinking that all solutions should be elegant, when in fact they don't have to be.
5) This lab may require the entire period because the prediction is so difficult. It will greatly benefit your students to go over the prediction very slowly, step-by-step without skipping any steps.
6) As a class exercise, test the extremes of the prediction equation. What happens when the central mass, M, goes to zero? to infinity? What is the maximum mass the hanging bridge can carry?

Difficulties and Alternative Conceptions:

- For the most part, students can accurately guess what will happen with this lab. The most important job you have is to show how mathematics and physics can apply to the system.
- Discuss the extremes of mass, and discuss why the frictionless pulley assumption becomes increasingly bad.
- Remind students that a net force is necessary to produce acceleration.

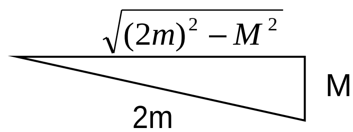
Prediction and Warm-up Questions:

No net vertical force so

$$Mg = 2T_y$$

where T_y is the vertical component of the tension of the 2 ropes on M. Letting θ be the angle between the horizontal and the rope we have

$$Mg = 2mg\sin\theta \;\Rightarrow\; \sin\theta = \frac{M}{2m}$$



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

$$d = \frac{L}{2}\tan\theta = \frac{LM}{2\sqrt{(2m)^2 - M^2}}$$

where M is the mass of object B, m is the mass of objects A and C, L is the distance separating the pulleys, and d is the vertical displacement of object B.

Possible Discussion Questions:

1) If you could not measure the distance of vertical displacement of object B, what other measurements could one take to test the prediction? (watch the rise of objects A and C)
2) What happens when M > 2m?
3) Would the mass of the rope ever come into play? How could you include the mass of the rope in your analysis?

Sample Data:

m_A = 119.12g; m_B = 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

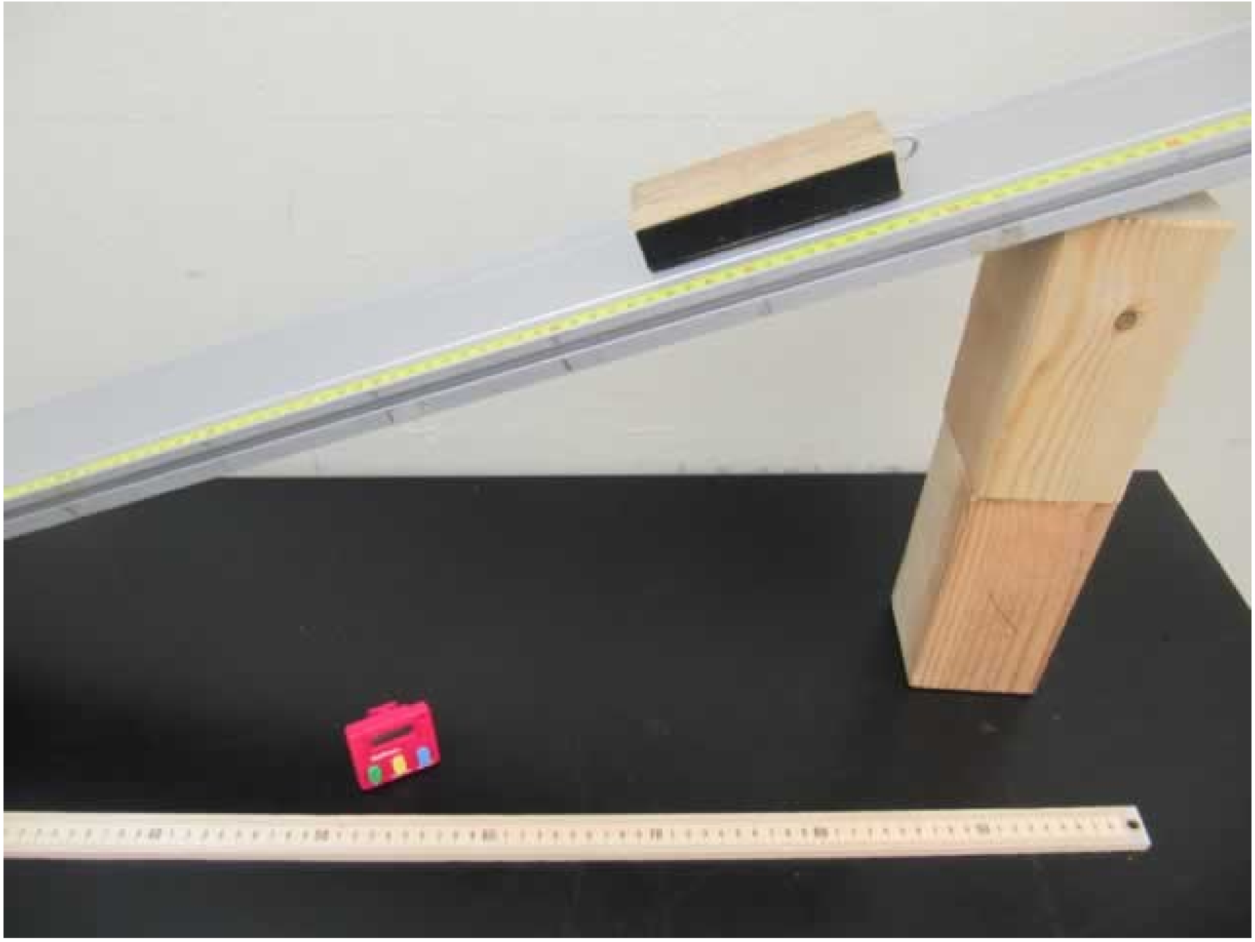
In the calculation of the predicted vertical displacement the average value of m_A and m_B was used for *m*.

Lab 3 Problems 3 and 4: Normal Force and the Kinetic Frictional Force

Purposes:

1) To determine how the normal force depends on mass and the angle of the incline.
2) To use a graph to find the coefficient of kinetic friction.

Equipment: track, cloth block, wood blocks, mass set, meter stick & masking tape. Additionally, a 26" aluminum plane (not shown) is included that allows for easier positioning and manipulation.



Teaching Tips:

1) These problems are almost identical in the manual. Assign half the students problem 3 and half of them problem 4, then compare results as a class at the end.
2) Have students try several different configurations before taking data. The block must accelerate smoothly, no sticking, for the results to make any sense.
3) Try tilting the board from the table all the way down to the floor to eliminate the sticking tendency.
4) Clean and dry the laminate before taking any data.
5) Be sure the students make the graph before leaving. Finding acceleration is no longer the end goal as it was in previous labs. Now they will use acceleration to calculate the normal and frictional forces.

Predictions and Warm-up Questions:

The slope of the frictional force versus the normal force gives the coefficient of kinetic friction.

$$f_k = mg\sin\theta - ma$$
$$N = mg\cos\theta$$

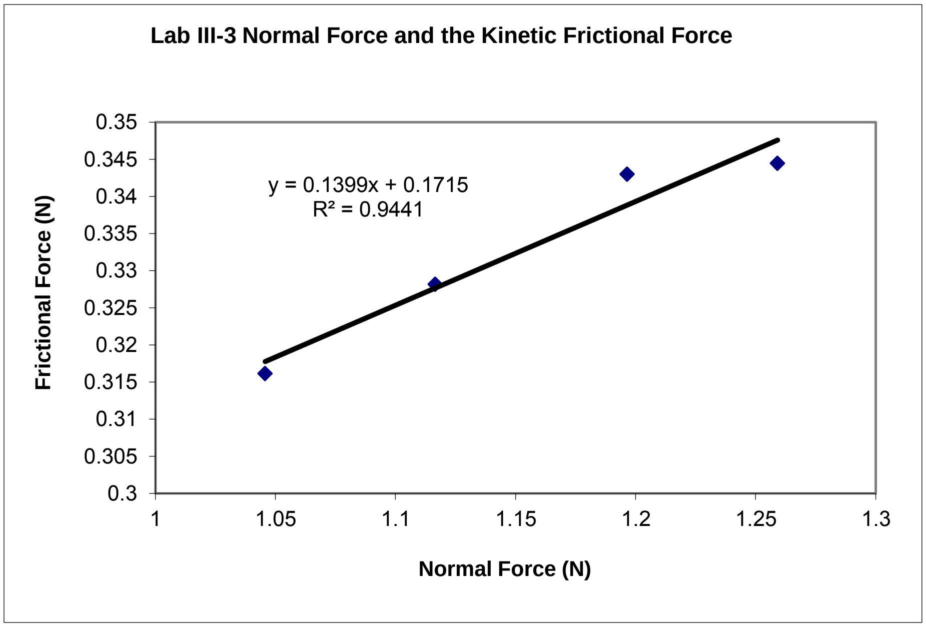
Possible Discussion Questions:

1) What are the sources of uncertainty in this problem?
2) Does changing the angle of incline change the coefficient of friction? Does changing the angle of incline change the normal force? How?

Sample Data:

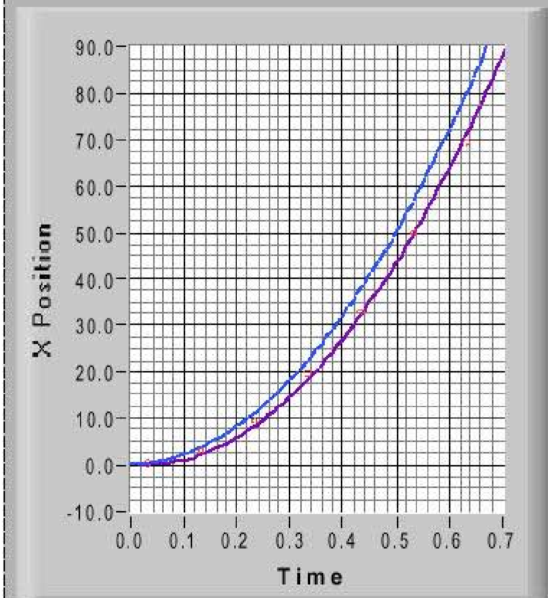
Problem 3:
Mass of the block: m = 137.53g

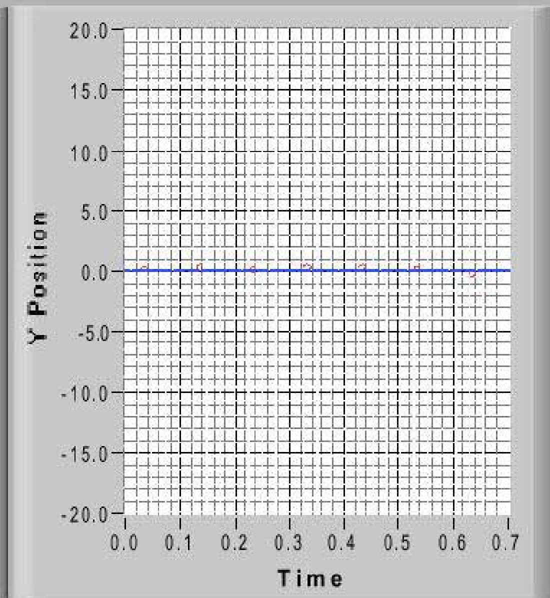
sin θ	Acceleration a (cm/ s^2)	Normal Force F_N (N)	Frictional force f_k (N)
0.6319	390.00	1.05	0.316
0.5613	312.00	1.12	0.328
0.4622	204.00	1.20	0.343
0.3593	102.00	1.26	0.344



Graph Title

Lab III-3a Normal Force & Frictional Force (0.6319)





X - Prediction Equation

u(t)=0.000 + 0.000t + 200.000 t^2

X - Fit Equation

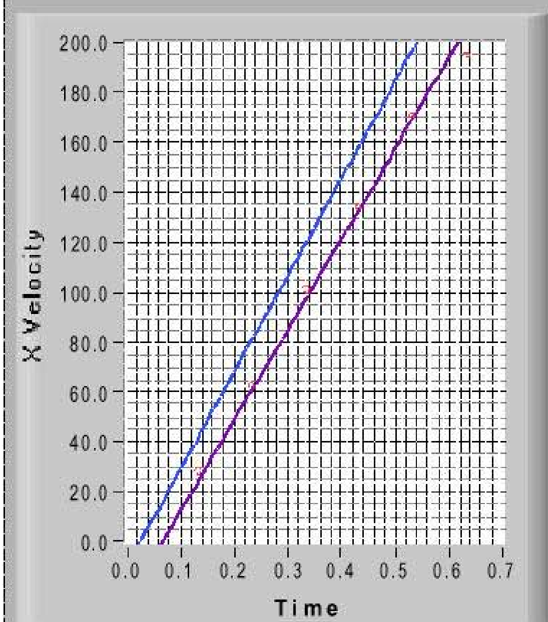
u(t) = 0.000 + -11.000 t + 195.000 t^2

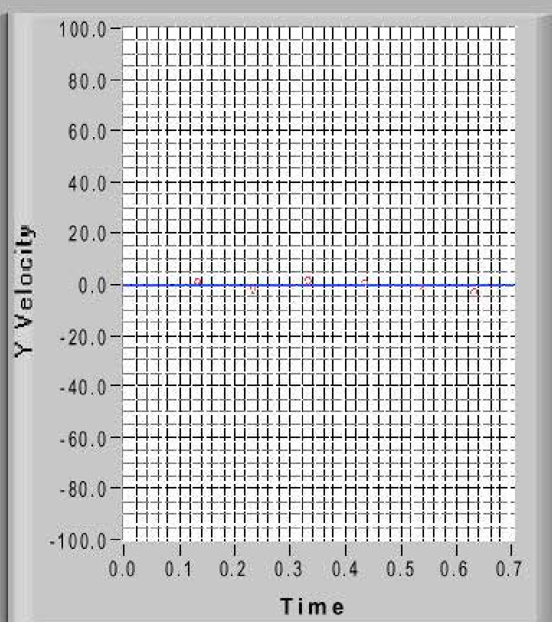
Y - Prediction Equation

u(t)=0.000 + 0.000t

Y - Fit Equation

u(t)=0.000 + 0.000t





Vx - Prediction Equation

u(t)=-11.000 + 390.000t

Vx - Fit Equation

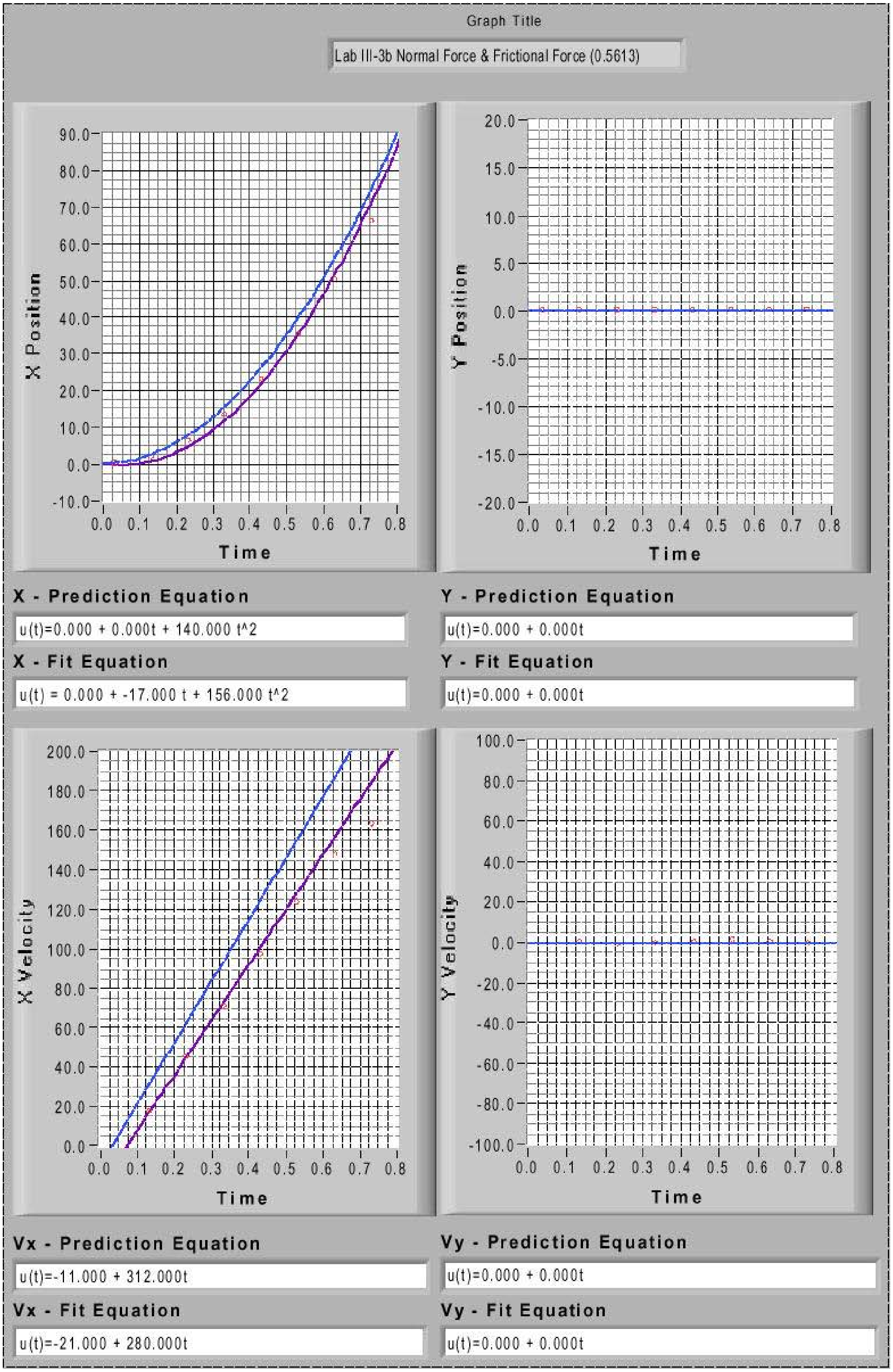
u(t)=-25.000 + 364.000t

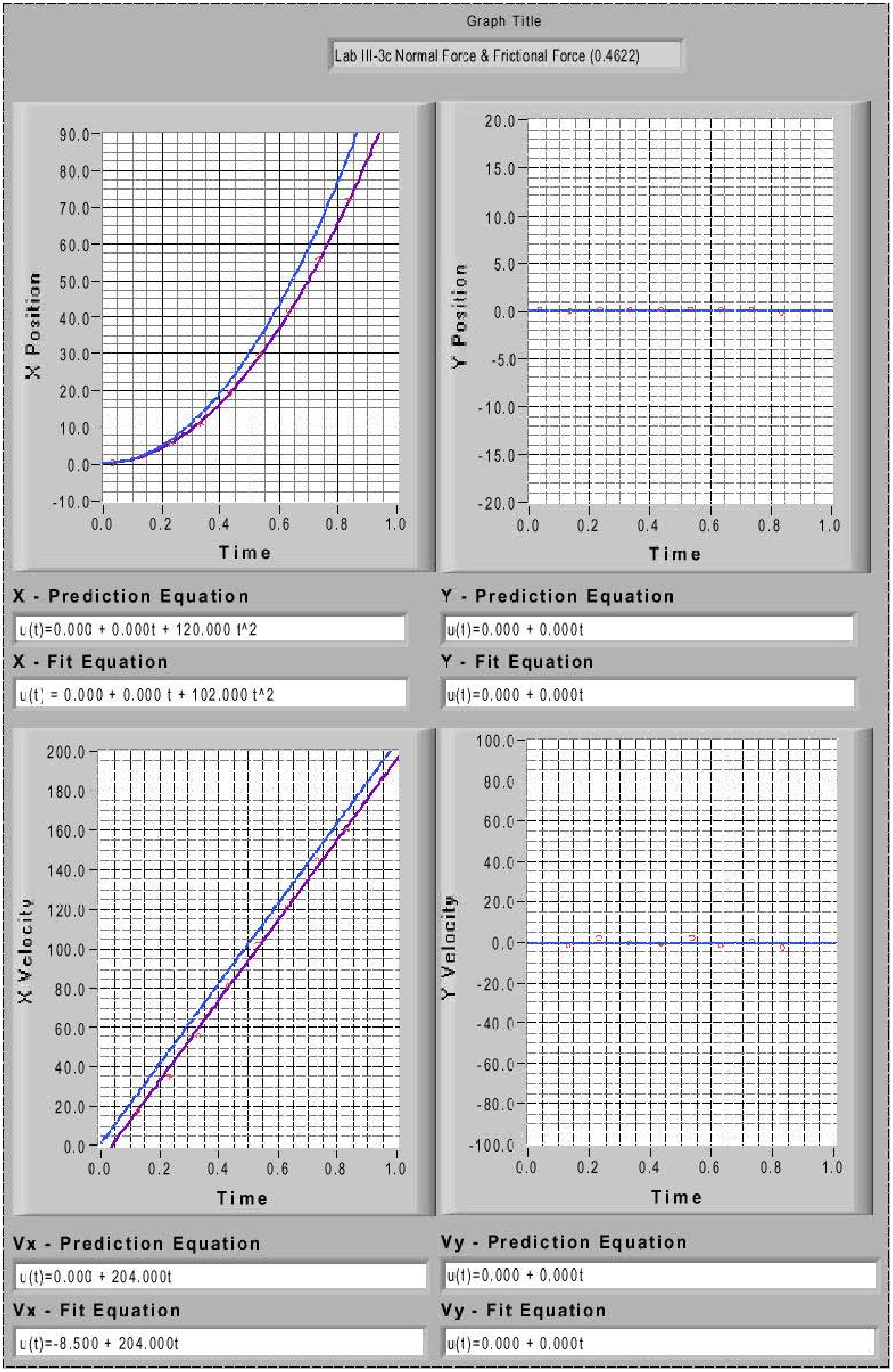
Vy - Prediction Equation

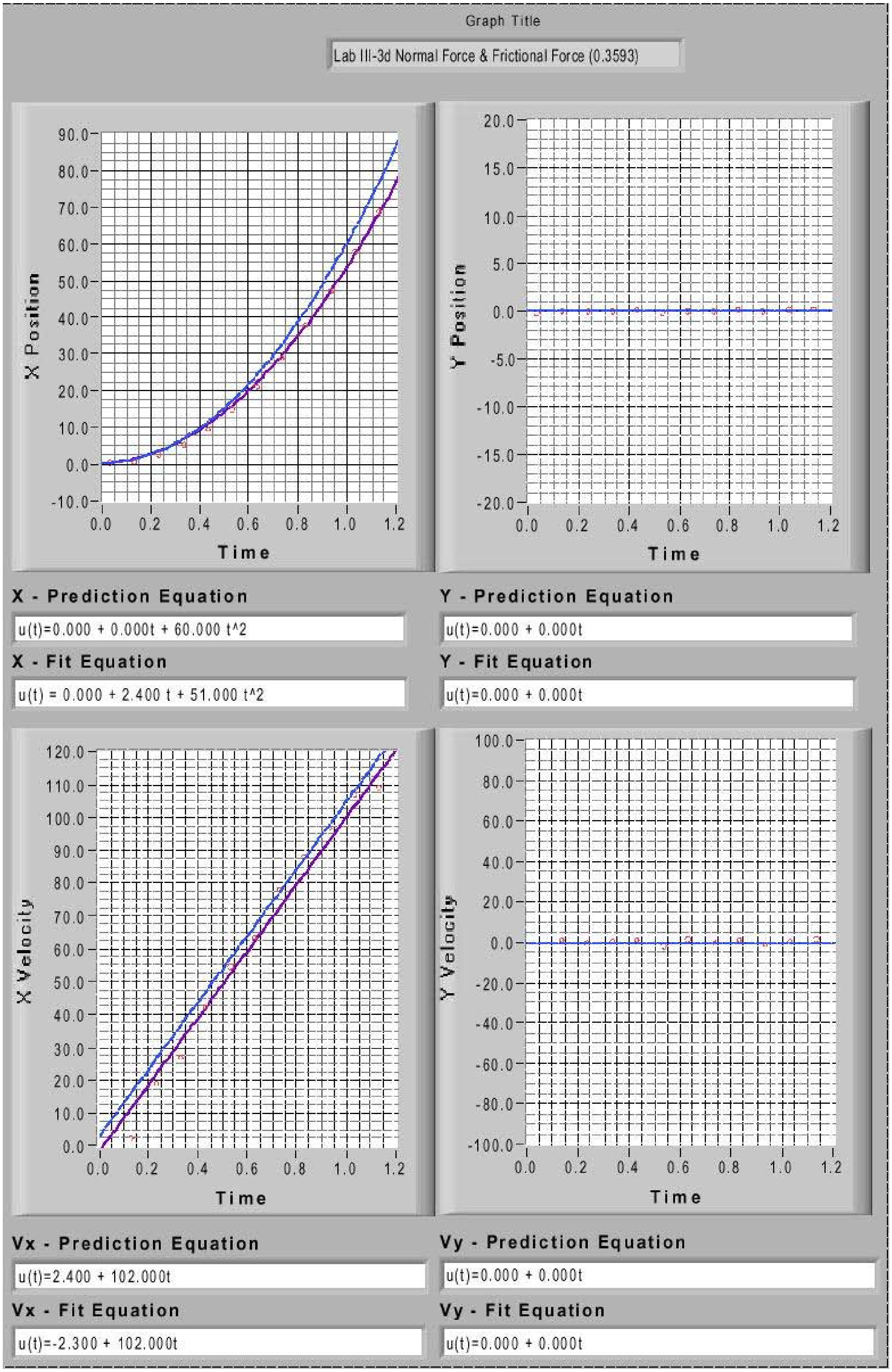
u(t)=0.000 + 0.000t

Vy - Fit Equation

u(t)=0.000 + 0.000t

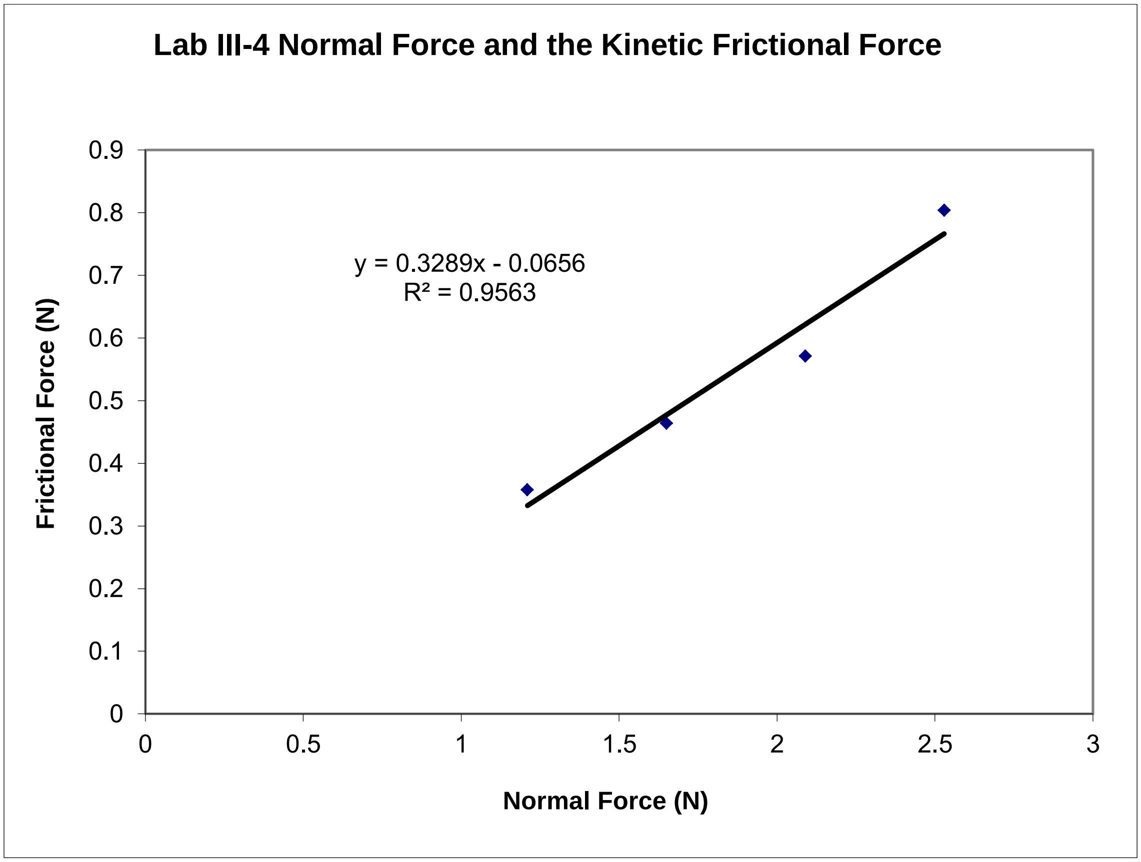

Graph Title
Lab III-3b Normal Force & Frictional Force (0.5613)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 140.000 t^2
X - Fit Equation
u(t) = 0.000 + -17.000 t + 156.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-11.000 + 312.000t
Vx - Fit Equation
u(t)=-21.000 + 280.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

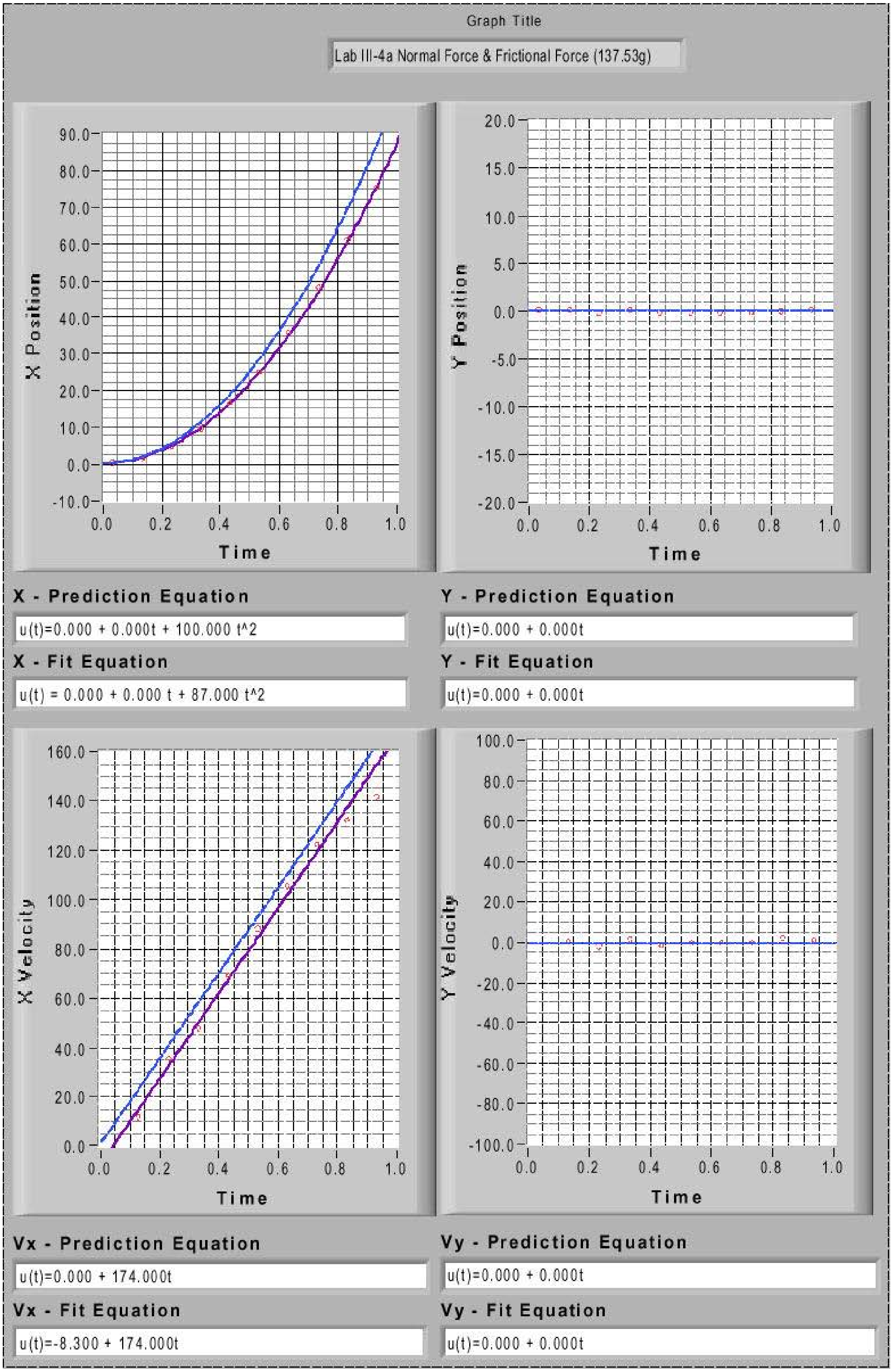

Graph Title
Lab III-3c Normal Force & Frictional Force (0.4622)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 120.000 t^2
X - Fit Equation
u(t) = 0.000 + 0.000 t + 102.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=0.000 + 204.000t
Vx - Fit Equation
u(t)=-8.500 + 204.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

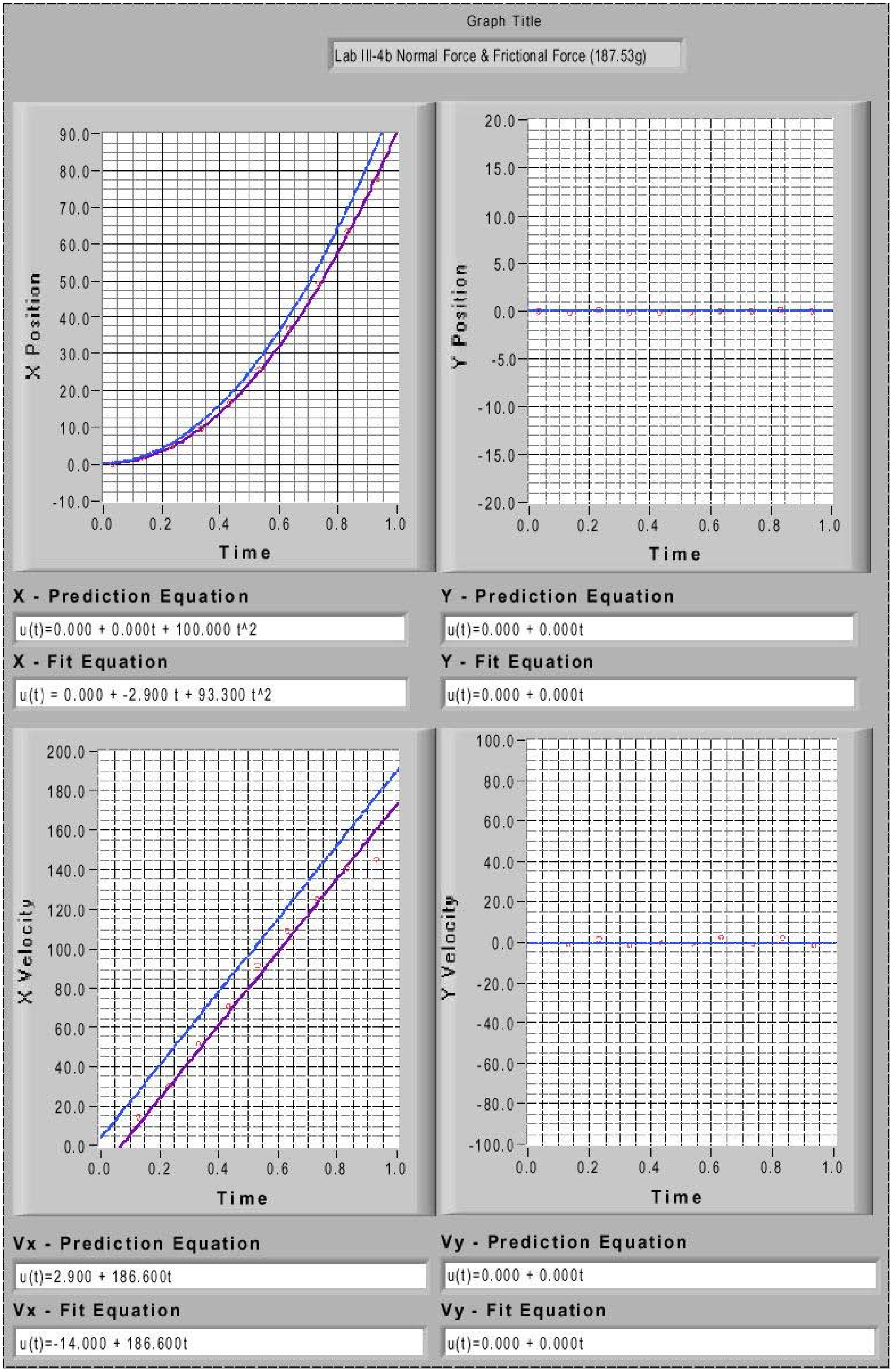

Graph Title
Lab III-3d Normal Force & Frictional Force (0.3593)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 60.000 t^2
X - Fit Equation
u(t) = 0.000 + 2.400 t + 51.000 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=2.400 + 102.000t
Vx - Fit Equation
u(t)=-2.300 + 102.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

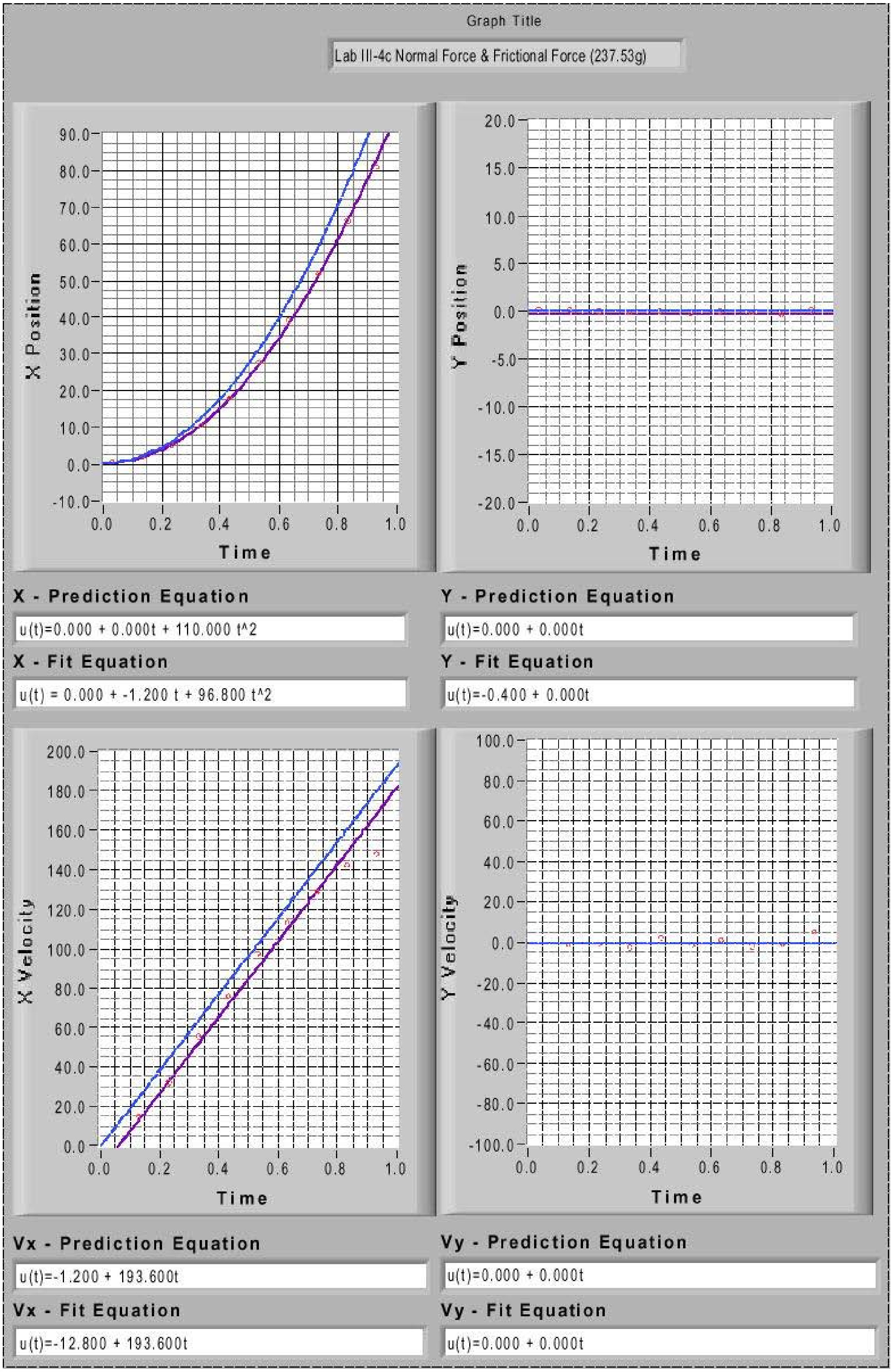
Problem 4:
sin θ = 0.4425g

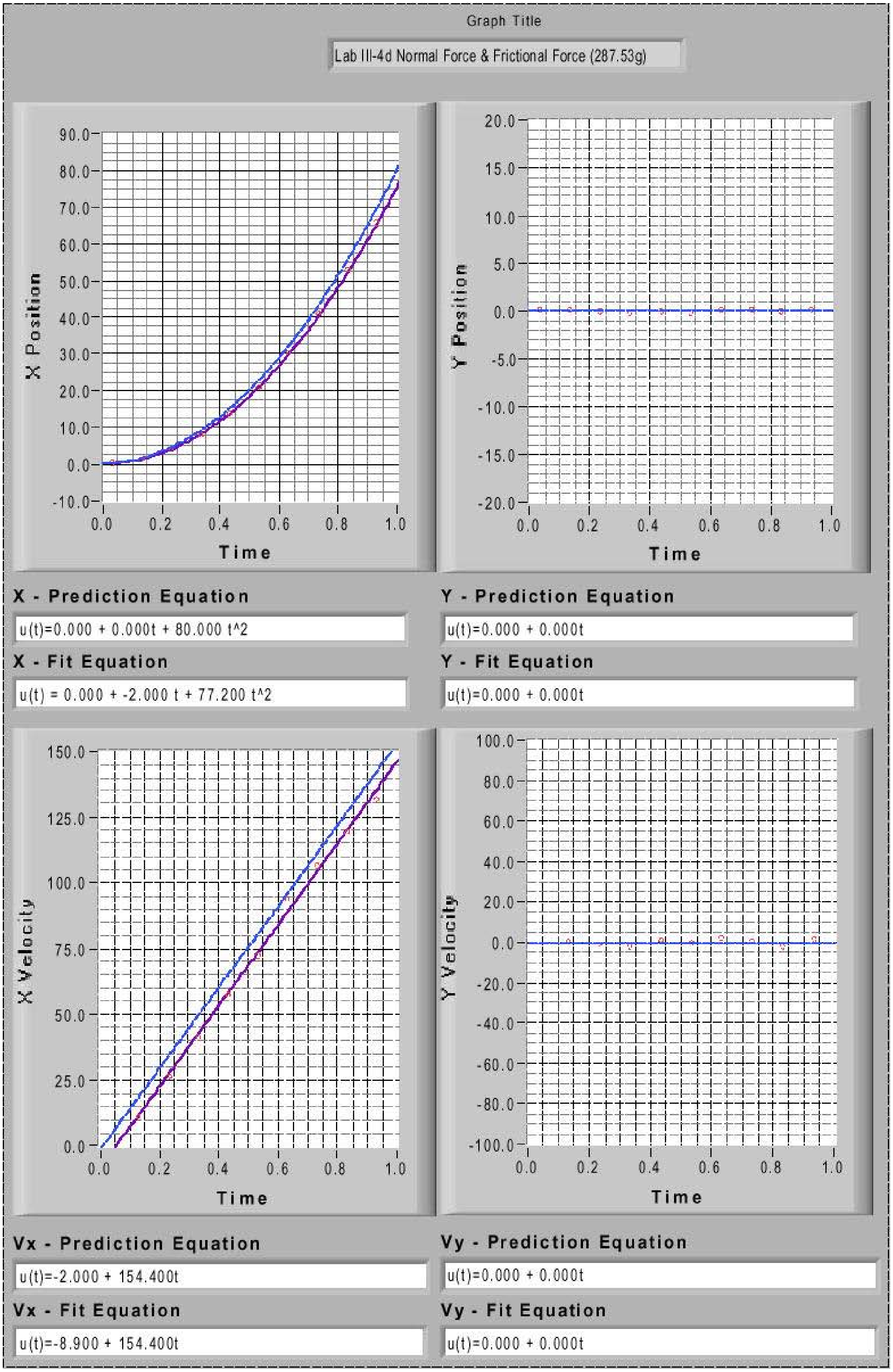
Mass m (g)	Acceleration a (cm/s^2)	Normal Force F_N (N)	Frictional force f_k (N)
137.53	174.00	1.21	0.358
187.53	186.60	1.65	0.464
237.53	193.60	2.09	0.571
287.53	154.40	2.53	0.804




Graph Title
Lab III-4a Normal Force & Frictional Force (137.53g)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 100.000 t^2
X - Fit Equation
u(t) = 0.000 + 0.000 t + 87.000 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 + 174.000t
Vx - Fit Equation
u(t)=-8.300 + 174.000t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab III-4b Normal Force & Frictional Force (187.53g)
X Position
Time
Y Position
X - Prediction Equation
u(t)=0.000 + 0.000t + 100.000 t^2
X - Fit Equation
u(t) = 0.000 + -2.900 t + 93.300 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Y Velocity
Vx - Prediction Equation
u(t)=2.900 + 186.600t
Vx - Fit Equation
u(t)=-14.000 + 186.600t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t


Graph Title
Lab III-4c Normal Force & Frictional Force (237.53g)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 110.000 t^2
X - Fit Equation
u(t) = 0.000 + -1.200 t + 96.800 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)=-1.200 + 193.600t
Vx - Fit Equation
u(t)=-12.800 + 193.600t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

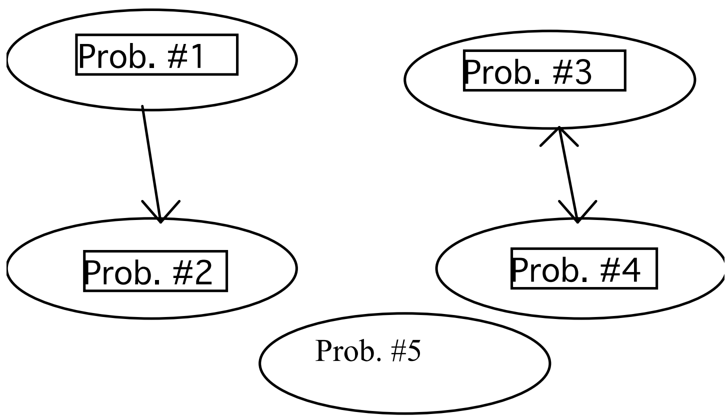

Graph Title
Lab III-4d Normal Force & Frictional Force (287.53g)
X Position
Time
Y Position
Time
X - Prediction Equation
u(t)=0.000 + 0.000t + 80.000 t^2
X - Fit Equation
u(t) = 0.000 + -2.000 t + 77.200 t^2
Y - Prediction Equation
u(t)=0.000 + 0.000t
Y - Fit Equation
u(t)=0.000 + 0.000t
X Velocity
Time
Y Velocity
Time
Vx - Prediction Equation
u(t)=-2.000 + 154.400t
Vx - Fit Equation
u(t)=-8.900 + 154.400t
Vy - Prediction Equation
u(t)=0.000 + 0.000t
Vy - Fit Equation
u(t)=0.000 + 0.000t

Laboratory 4: Circular Motion

Laboratory 4 combines the special case of centripetal force with previous discussions of position, velocity, and acceleration. Continue to discuss the differences between instantaneous and average velocities and accelerations.

You may wish to remind your students that circular motion is not exclusive to quirky examples such as a whirling stopper on a string. Circular motion exists all around us. Bicycles, spinning propellers, rotating galaxies, and orbiting planets are all examples of circular motion. Even the motion of objects that do not make complete circles can be understood with knowledge of circular motion, objects such as falling smokestacks, or ice-skaters rounding a curve.

In later labs, your students will see that circular motion is useful in describing simple harmonic motion.



General Teaching Tips:

1) Circular motion is difficult for students to grasp. Remind them that we are still using standard analysis techniques. Nothing is new.
2) Spend time on the force diagrams. Tell students that all the forces pointing towards the center of rotation constitute the centripetal force.
3) Problems 3 and 4 are almost redundant. They should be split among groups in the class.
4) If time permits, challenge your class with "Check your understanding" questions. They are good source of practice for the exam.

Things to Remember:

1) Email labhelp@physics.umn.edu to report any equipment problems or issues.
2) 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 lab students should be able to:

1) Describe the magnitude and direction of acceleration for objects moving perfect circles with uniform speeds.
2) Use force diagrams and the concept of centripetal force to predict the behavior of objects in circular motion.

Things to check fifteen minutes before lab:

1) Test the frictionless assumption by watching how fast the spinner halts after spun by hand.
2) Untangle the whirling devices from the stoppers and the washers.

Below is a frame of 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, thus we will not lose any data points due to blocking of the picture by the tripod or other objects.

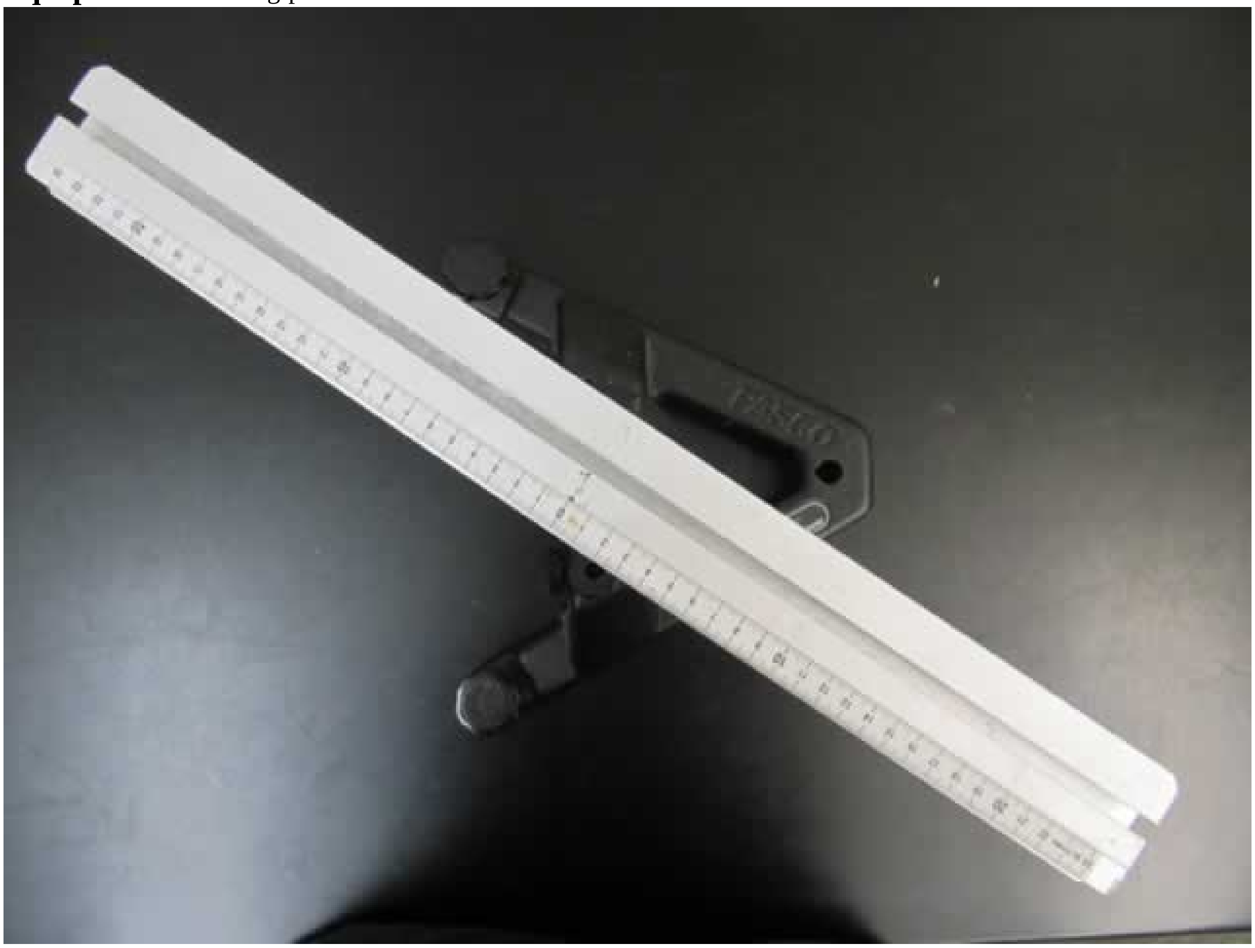
To get these problems to work properly the students MUST use the arm of the spinning apparatus to calibrate their movie.

Lab 4 Problem 1 and 2: Circular Motion and Acceleration

Purposes:

1) To determine the direction and magnitude of an object in uniform circular motion.
2) To learn how the graphs of instantaneous position, velocity and acceleration are intimately connected. (i.e. through slopes of tangents)

Equipment: rotating platform and base



Teaching Tips:

1) Since students will use the same data for both problems, make sure that you approve the data before they set off on problem 1. Remind students to export their data before quitting the video analysis program.
2) Although you are dealing with a non-constant acceleration, it is fair to approximate average quantities as the average of the instantaneous quantities halfway between the time intervals.
3) Remind your students that they are using the same numerical and graphical analysis that they already know, even though the situation in new and complex. Ask them to interpret the sinusoidal pattern as they graph position, velocity, and acceleration of each component.
4) Starting the analysis off center is perfectly fine. The sine and cosine curves, curves that betray a changing velocity, will be preserved even if they are displaced from the axis.
5) Draw the vectors in problem 2. Encourage the use of rulers and letting the length of a vector indicate its magnitude.

Difficulties and Alternative Conceptions:

- Most students believe that constant speed means zero acceleration. Remind them that the direction of velocity is always changing, and therefore there has to be an acceleration.

- You can discuss the tension in the string that keeps the blocks from flying apart. This tension means there is a net force towards the center of the circle, and with net force there is an acceleration.

Predictions and Warm-up Questions:

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

Possible Discussion Questions:

1) What might we do to improve the precision of these problems?
2) If the direction of acceleration is towards the center of the circle, then how come I feel "thrown" to the outside when I take a curve in my car? (Answer: Because your seat is accelerating towards the center of the curve and your body is reacting to that acceleration. Your body has the inertia to keep going in the same direction, but you seat is accelerating in a different direction.)

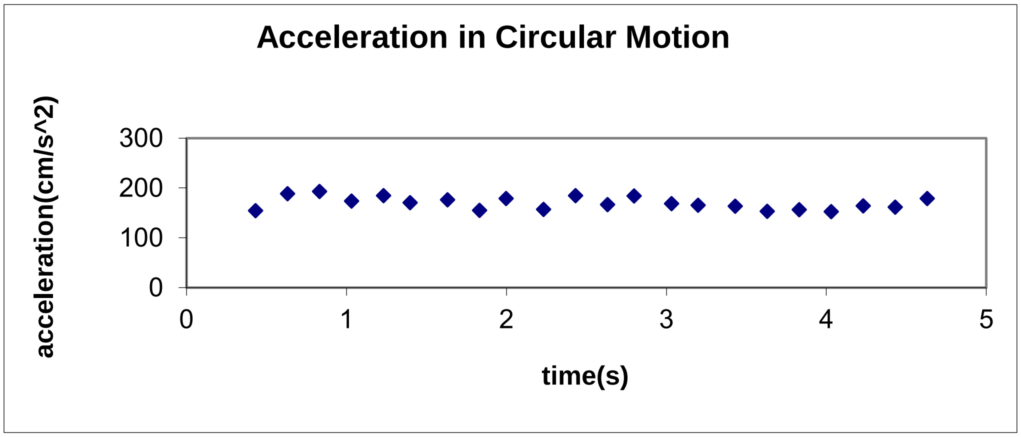
Sample Data and Results:

The data are based on the exported data from MotionLab for both problem 1 and problem 2.

In order for to get a table with approximately constant magnitude of acceleration be sure your students take data at equal time Intervals. I found that .2 seconds for about two periods is works well. This is because the times given on exported data usually have skipped frames or are wrong. Tell your students to change the times appropriately such that Interval between two points is the same.

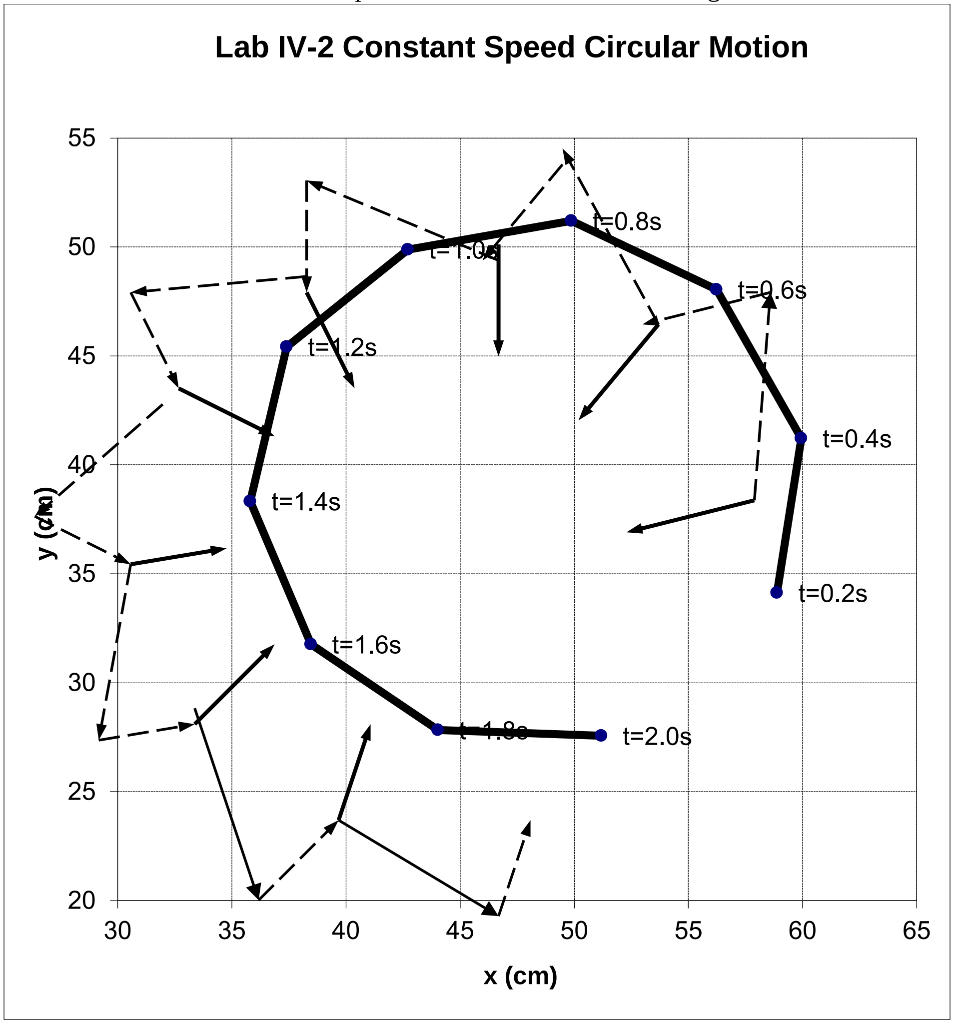
Time(s)	X position (cm)	Y position (cm)	X velocity (cm/s)	Y velocity (cm/s)	X acceleration (cm/s^2)	Y acceleration (cm/s^2)	magnitude of acceleration
4.63	-14.97	3.10	6.92	-50.39	158.20	82.65	178.49
4.43	-13.58	-6.98	38.56	-33.86	49.98	153.15	161.10
4.23	-5.87	-13.75	48.55	-3.23	-50.93	155.85	163.96
4.03	3.84	-14.39	38.37	27.95	-126.20	85.40	152.38
3.83	11.51	-8.80	13.13	45.03	-155.85	4.15	155.91
3.63	14.14	0.20	-18.05	45.86	-112.88	-103.20	152.94
3.43	10.53	9.37	-40.62	25.22	-40.93	-158.18	163.38
3.20	2.40	14.42	-48.81	-6.42	83.40	-142.23	164.87
3.03	-7.36	13.13	-32.13	-34.87	144.50	-85.93	168.12
2.80	-13.78	6.16	-3.23	-52.05	175.78	53.28	183.67
2.63	-14.43	-4.25	31.93	-41.40	77.35	147.55	166.60
2.43	-8.04	-12.53	47.40	-11.89	-13.45	183.80	184.29
2.23	1.44	-14.91	44.71	24.88	-121.25	99.77	157.02
2.00	10.38	-9.93	20.46	44.83	-178.65	9.60	178.91
1.83	14.47	-0.97	-15.27	46.75	-130.70	-83.43	155.06
1.63	11.42	8.39	-41.41	30.07	-32.13	-172.93	175.88
1.40	3.14	14.40	-47.84	-4.52	55.38	-160.75	170.02
1.23	-6.43	13.49	-36.76	-36.67	167.68	-76.90	184.47
1.03	-13.78	6.16	-3.23	-52.05	166.50	48.68	173.47
0.83	-14.43	-4.25	30.08	-42.32	105.20	161.33	192.59
0.63	-8.41	-12.71	51.12	-10.05	-36.38	184.40	187.95
0.43	1.81	-14.72	43.84	26.83	-121.33	94.95	154.06
0.23	10.58	-9.36	19.58	45.82			
0.03	14.49	-0.19					
			Average magnitude of acceleration			169.32cm/s^2	

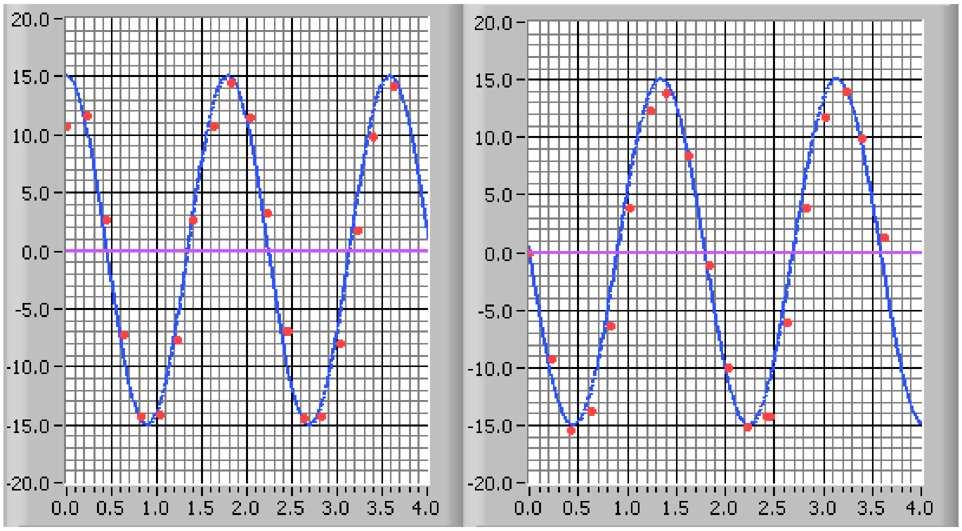
Velocities and accelerations are averages taken from the position data points. Notice one less data point every time you are taking an average!
Measured radius of rotation: 15 cm



Problem 2:

The direction of acceleration for each data point is shown in the following chart.



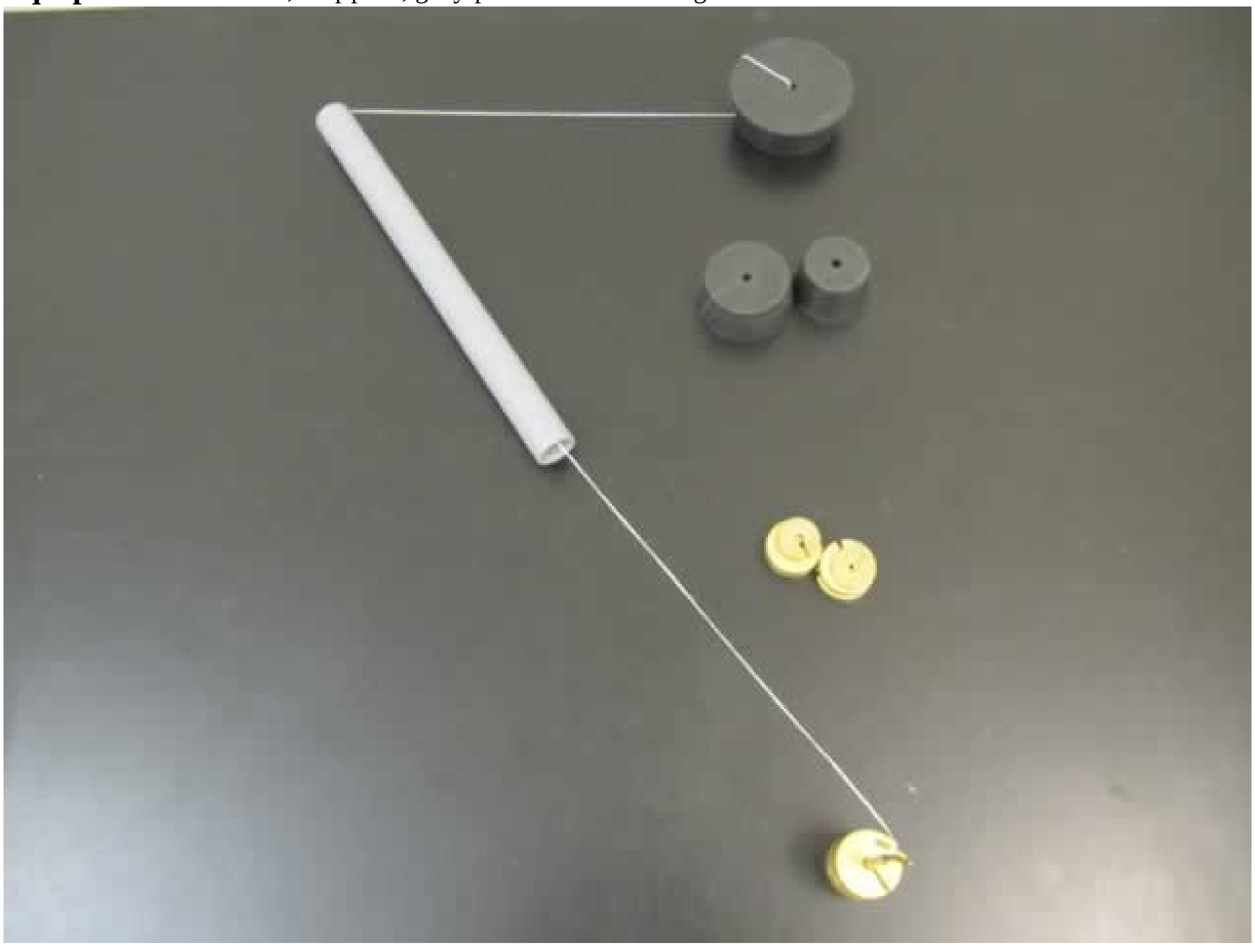


Lab 4 Problem 3 and 4: Rotational Period and Force

Purposes:

1) To use force diagrams in understanding circular motion.
2) To build on the students' knowledge of centripetal acceleration.
3) To introduce the concept of rotational period.

Equipment: mass set, stoppers, grey pvc handle & string



Teaching Tips:

1) Problem 3 asks students to change the hanging masses; problem 4 asks them to change the mass of the rubber stopper. You do not have to complete both problems since they are so similar. Do spend time on one, however. You will find the results quite true to the prediction.
2) Spend time on the prediction and Warm-up questions. These concepts are new to many students, and they will still have difficulty seeing how to use the force diagram.
3) For the advanced groups, you may want to discuss why the stopper can never travel in a perfectly horizontal path. (A vertical component of the tension is always needed to balance the stopper's weight.)
4) There is a fair amount of friction present when using the heavier masses. Ask your students to see if the uncertainty increases.
5) Wear goggles or other eye protection. Some groups can move into the halls if they like.

Prediction and Warm-up Questions:

T = period of rotation
L = length of string from handle to stopper
M = hanging mass
m = mass of stopper

The tension of the string on the stopper is equal to the weight of the hanging mass. Since this tension keeps the stopper in circular motion we have

$$Mg = \frac{mv^2}{L}$$

where v, the velocity of the stopper can also be written

$$v = \frac{2\pi L}{T}$$

eliminating v from the first equation and solving for the period we have

$$T = 2\pi\sqrt{\frac{mL}{Mg}}$$

Possible Discussion Questions:

1) If the Olympic athlete increased the length of their hammer and whirled it with the same force, would they increase or decrease the speed of the hammer?
2) In what other situations can we use knowledge of rotational period and centripetal force? (Remember, the end goal is not to understand the motion of just the stopper connected to a string. The end goal is to make students better problem solvers and help them understand the physics that apply to the situation. Then they can extend their knowledge to other situations.)

Sample Data and Results:

Problem 3:

m, stopper:=13.6 g *L*, length of the string:22cm

M, hanging mass (g)	*T*, measured (s)	*T*, Predicted (s)	% difference
25.9	0.63	0.68	7.66
41.4	0.53	0.54	1.79
51.7	0.49	0.48	1.47
67.1	0.44	0.42	3.80

Problem 4:

M,hanging mass=13.6g *L*, length of the string=25cm

M, stopper(g)	*T*, measured (s)	*T*, Predicted (s)	% difference
65.7	.74	.73	1.37
54.7	.64	.66	3.03
34.4	.51	.53	1.92

Lab 4 Problem #5: Torque and Equilibrium

Purpose: To calculate the conditions for static torque equilibrium of a system.

Equipment:

Meter sticks and mass set

Teaching Tips:

- The students will likely get stuck in the warm up questions since there are many things that they need to define about the system and since the constraints may confuse them. They will probably need to work out how to do the problem in their groups before they perform the lab. The actual measurement is very quick and easy, so you can let them spend the time with the theoretical calculations.
- You may want to define common terms on a diagram at the beginning of lab so that everyone is using the same variables. This will help them talk to each other about what they are doing, and it will help you follow their steps more easily.

Predictions and Warm Ups:

One mass with meter stick:

- Constraint necessary:
    - $m_1 = 2m_{stick}$

$$\tau_1 = \tau_{stick}$$
$$m_1 x_1 = m_{stick} x_2$$
$$\text{Assuming } m_1 = 2m_{stick}$$
$$\frac{x_2}{x_1} = 2$$

where
$m_1 =$ only mass
$m_{stick} =$ mass of meter stick
$x_1 =$ distance of m_1 from balance point
$x_2 =$ distance of 50cm from balance point

Two masses with meter stick:

- Constraints necessary:
  - Masses are equidistance from 50 cm mark
  - The distance between the masses is known

$$\tau_1 = \tau_2 + \tau_{stick}$$
$$m_1 x_1 = m_2 x_2 + m_{stick} x_3$$
$$x_1 + x_2 = l$$
$$l/2 = x_1 + x_3$$
$$x_1 = \frac{(m_2 + \frac{m_{stick}}{2})l}{(m_1 + m_2 + m_{stick})}$$
$$x_2 = \left(1 - \frac{(m_2 + \frac{m_{stick}}{2})}{(m_1 + m_2 + m_{stick})}\right)l$$
$$x_3 = \left(\frac{1}{2} - \frac{(m_2 + \frac{m_{stick}}{2})}{(m_1 + m_2 + m_{stick})}\right)l$$

where
$x_1 =$ distance of m_1 from balance point
$x_2 =$ distance of m_2 from balance point
$x_3 =$ distance of 50cm from balance point
$l =$ distance between m_1 and $m_2 =$ known

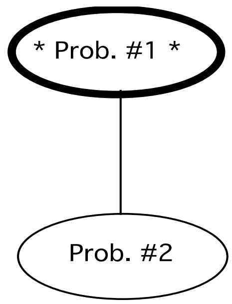
Possible Discussion Questions:

1) How many locations can the masses be placed and still have the system balance?
2) What is the determining factor for balance? Is it location of the masses? The difference in the masses?
3) What happens to the balance point as the mass increases in the one mass system? As it decreases?
4) What happens to the balance point as the masses increase in the two mass system? As it decreases?

Laboratory 5: Measuring Spring Constants

This lab will focus on Hooke's law-type forces, where the force is proportional to the distance from equilibrium. This lab will only use the static approach for finding the spring constant. There may be references to the dynamic approach in this lab.

This is the flow chart for Laboratory 5.



By the end of lab students should be able to:

1) Experimentally measure the spring constant of various springs and in different configurations using Hooke’s law.

Things to check fifteen minutes before lab:

Check the mass limits so as not to damage the spring.

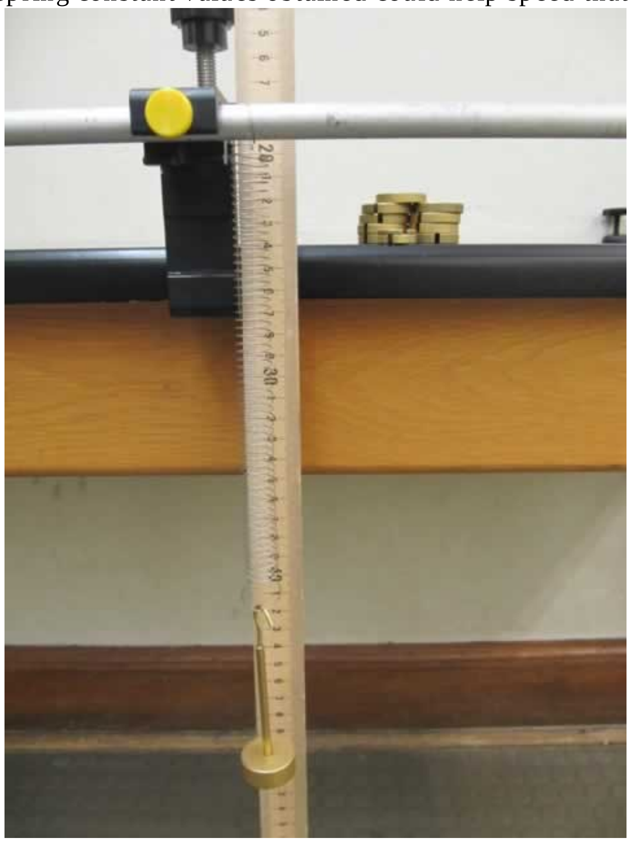
NOTE: the compression springs used in lab 5 problem 1 are the same springs provided in lab 6 problem 1 – IMPULSE AND CHANGING MOMENTUM.

Lab 5 Problem #1: Measuring Spring Constants

Purpose:

1) To introduce Hooke's law and find the spring constant.

Equipment: compression springs are also included. These are the same springs used in lab 6 (problem 1), so the spring constant values obtained could help speed that difficult problem up.



Things to Remember:

1) The students may not remember Hooke's law. It is in the assigned reading, so **DO NOT LECTURE**. Instead refer them to their textbook.

Difficulties and Alternative Conceptions:

- This is the students' first experience with a non-constant force. It may not be as intuitive for them as you might expect. Ask your students to explain the negative sign in Hooke's law.

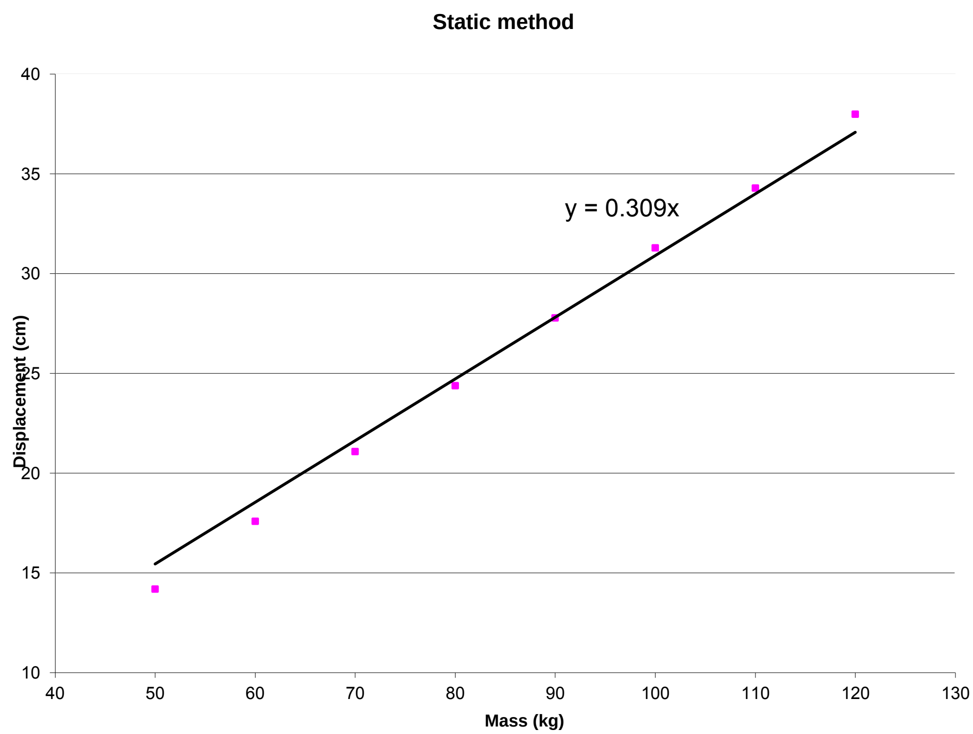
Predictions and Warm-up:

Sample Data

Static Approach

Measuring the spring constant works well in both the static and dynamic method, however, we will only use the static approach. One problem your students might have is trying to calculate the spring constant from individual data points. Have them plot the data and ask them how they can use that to find the spring constant. They may have trouble relating the spring constant to the slope of the graph. Below is the data and a graph from a sample experiment. All displacements were taken from a rest position where there was no load.

Mass (g)	Displacement (cm)
50	14.2
60	17.6
70	21.1
80	24.4
90	27.8
100	31.3
110	34.3
120	38



$$\sum F = k\Delta x - mg = 0 \rightarrow \Delta x = \frac{g}{k}m$$

Therefore, the slope of this graph is g/k. Thus, the spring constant is 3171 g/s^2, or 3.171 N/m.

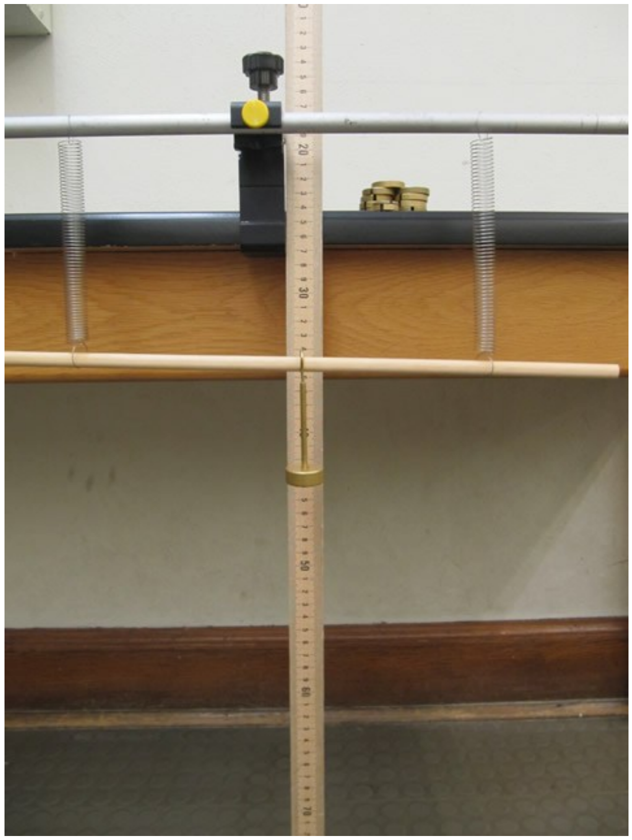
Possible Discussion Questions:

1) We just finished studying conservation of energy. Can you describe a new form of energy in the system of spring and mass? (potential energy of the spring)

Lab 5 Problem #2: The Effective Spring Constant

Purpose:

1) To apply the method of adding forces in a more complex environment and help students understand non-constant forces and acceleration.



Teaching Tips

1) This problem takes advantage of the results of problem #1. The students cannot do this problem without first having done problem #1.
2) Effective spring constants are not discussed in the text. You may need to sell the class on the advantages of this concept **at the end of the lab**.
3) Use the dowel rods to keep the parallel springs separated so they don't tangle.
4) The prediction for the parallel springs should be solved assuming that the amount of stretch of each spring is the same. If this assumption is not made, the only way to solve the problem is to consider the torque on the rod.

Difficulties and Alternative Conceptions:

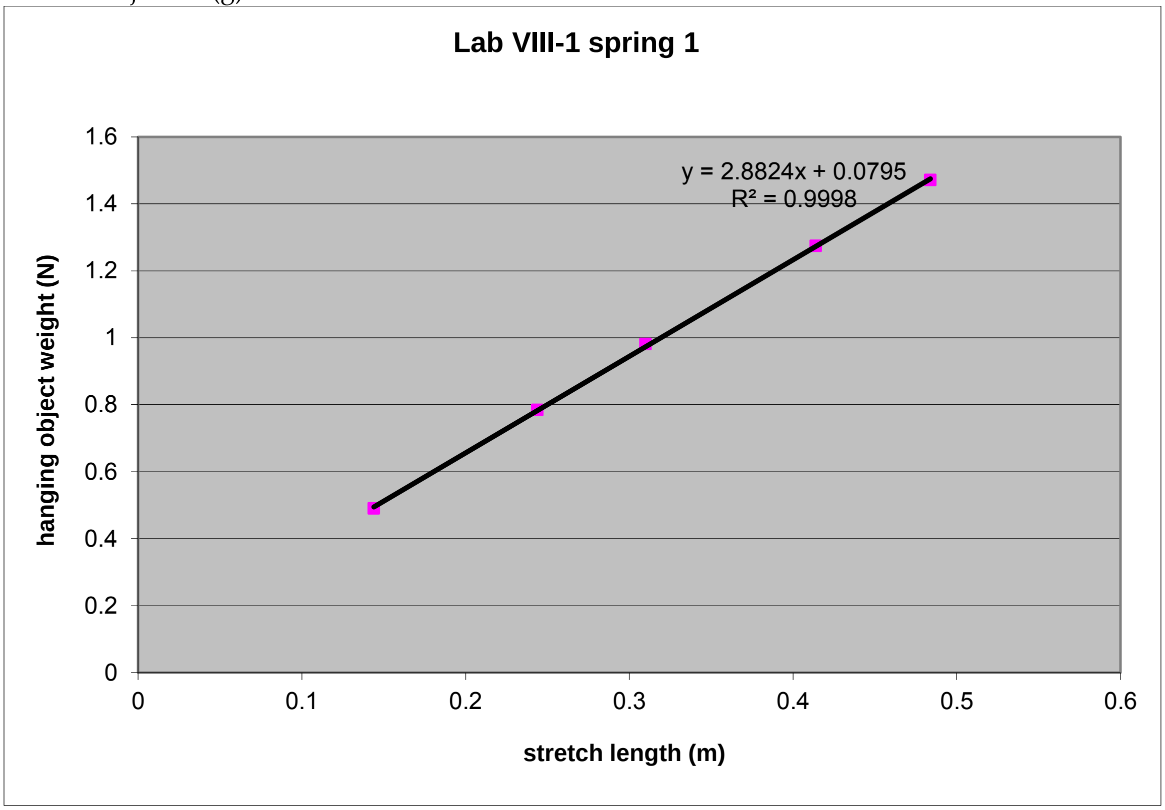
- This is the student's first experience with adding non-constant forces.

Prediction and Warm-up:

End-to-end: $k_{eff} = \dfrac{k_1 \cdot k_2}{k_1 + k_2}$ Side-by-side: $k_{eff} = k_1 + k_2$

Data

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).

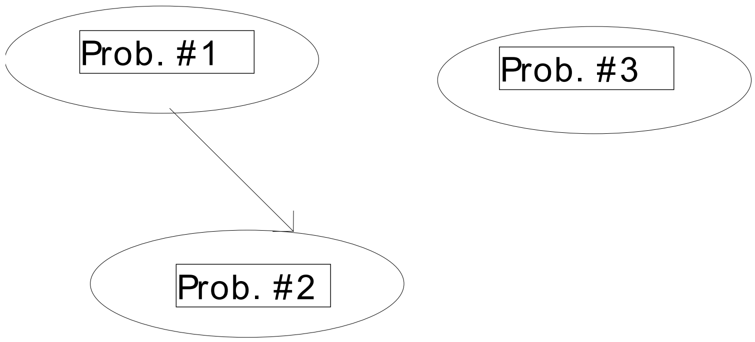
Possible Discussion Questions:

1) How would accounting for the mass of the springs affect our results?
2) How the potential energy of the spring system change when it is in a new configuration?

Laboratory 6: Impulse and Momentum

In laboratory 6 students will analyze collisions with the cognitive tool of momentum. There are only three problems in this lab. Much like the concept of energy, momentum is important because momentum is conserved in any interaction. The gigantic particle colliders, although more intricate in computation and equipment rely on the conservation of energy and the conservation of momentum just like these lab problems do.

By now, students are growing tired of the video and the analysis software; though, in most of these labs, they can skip many of the predictions and fit steps with the software. Keep your enthusiasm high. Remind students of the bigger picture and why their work with the videos is important. They are using a model to understand larger concepts that can be applied to different situations.



General Teaching Tips:

- push the students to think about what they need to measure in these labs and push them to be creative about how they acquire the data. The analysis software can be used without going through all of the steps if all the students need for a particular lab is a velocity reading.

Things to Remember:

1) Email labhelp@physics.umn.edu to report any equipment problems.
2) 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 lab students should be able to:

1) Understand the principles of conservation of energy and conservation of momentum, and how they apply to simple collisions in one-dimension.
2) Strengthen their predictive skills and skills of qualitative measurement.

Things to check fifteen minutes before lab:

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

- Make sure that all of the carts roll smoothly. Request replacements for any that have been damaged.

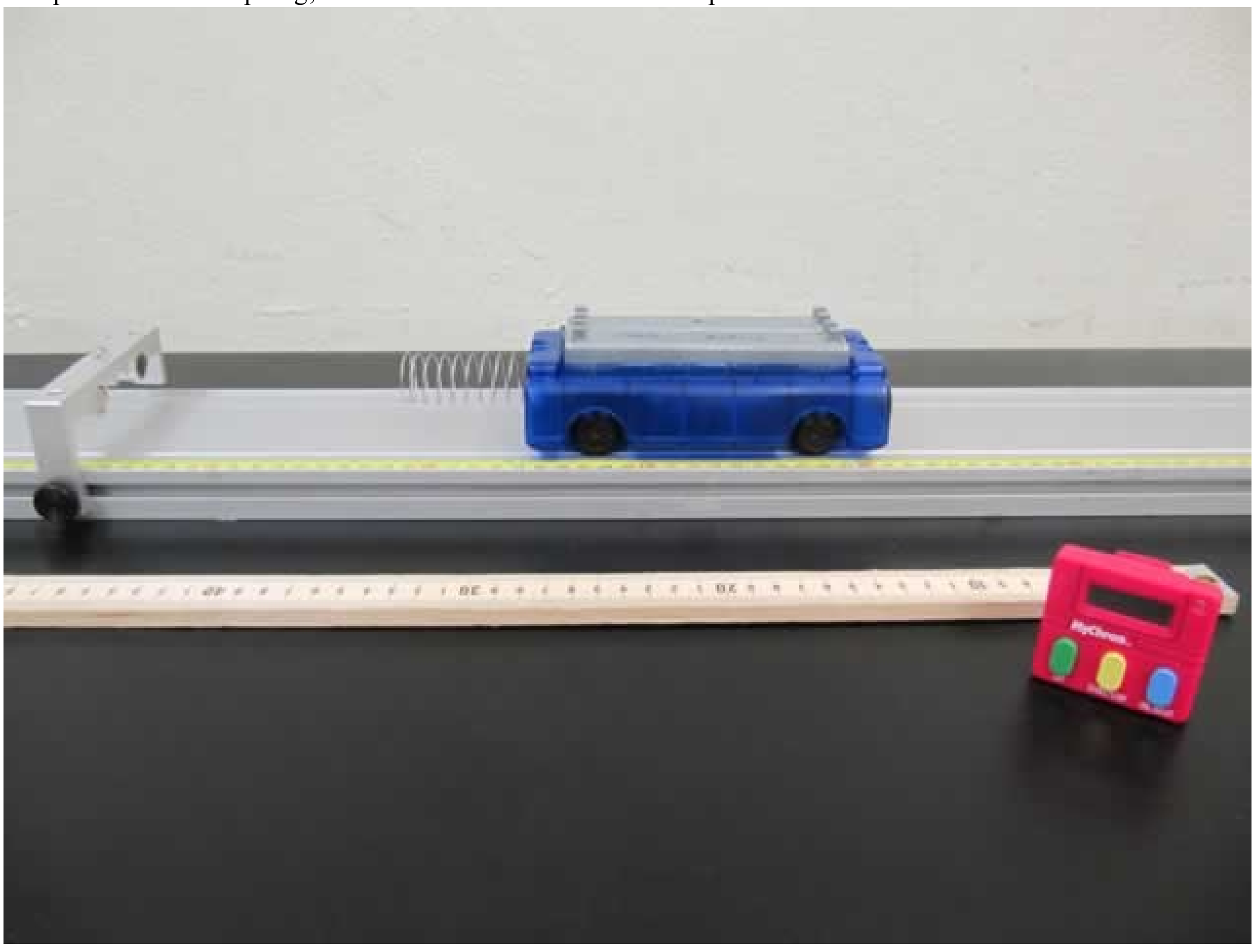
Lab 6 Problem #1: Impulse and Changing Momentum

Purpose:

1) To experimentally compare the two sides of the impulse-momentum theorem.

Equipment:

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



Teaching Tips:

- This is a newer lab, and it has the students use the video software in two unique ways. First, they analyze the video for the information about the compression of the spring, and, second, they use the analysis software to acquire information concerning the initial and final velocities of the collision with the end.
- The videos need to be close enough to the end point that they can read the millimeter marks on the meter stick and also they need a couple of frames of the carts motion before and after. You may want to discuss what information they are getting from the videos at the beginning of lab.
- For the velocities, they do not have to put in any predictions, or even fit equations! Stop them if they are trying. Help them figure out how many data points they need in order to get one velocity reading. This trick will help them in the other momentum labs.
- For the impulse side of the equation, they may have difficulty understanding what the graph should look like so give them some help with this. The book does a decent job covering the "integral" or area under the Force vs. time curve. *Don't bring up the integral with the whole class. Individual students may know what's going on, but the class as a whole is not expected to know it.*

- The preliminary runs seem to indicate that the separate calculations are within ~10% of each other. The lab tells them to consider the change in momentum to be the "theoretical" value as it is the one with the least amount of estimation.
- The mass of the cart and the length of the collision do not appear to produce different results.
- They should use their methods of finding the spring constant that they developed in the last lab. The springs on the carts are likely the same as the compression springs. That is a good confirmation that they measured the 'k' value correctly. They can put the cart on an inclined plane and add masses to incorporate Hooke's Law but make sure they take the angle of the plane into account in their calculation.
- You could have every group write their k values on the board so that the class can determine an average deviation assuming that all of the springs have approximately the same spring constant.
- The important part about this lab is that they see the separate calculations yield the same results. Physics works like we are expecting, and everyone is happy about it.

Predictions and Warm Ups:

Impulse:

$$J = \sum F \Delta t$$

Change in momentum:

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

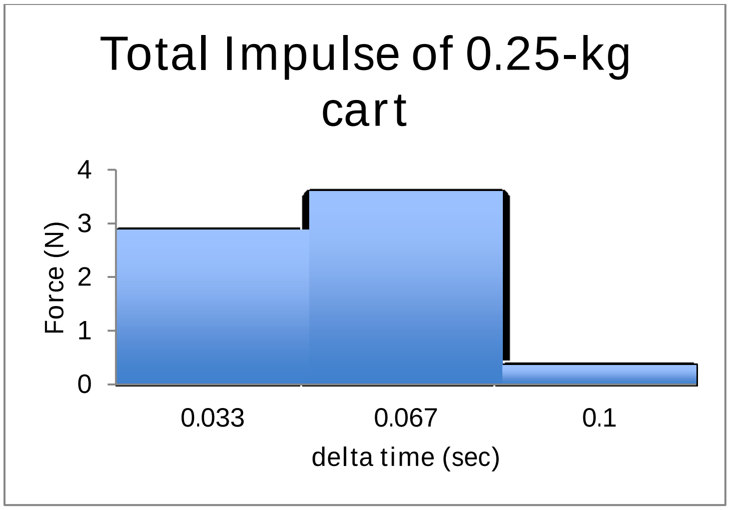
Hooke's Law:

$$F = k\Delta x$$

Data:

Trial 1

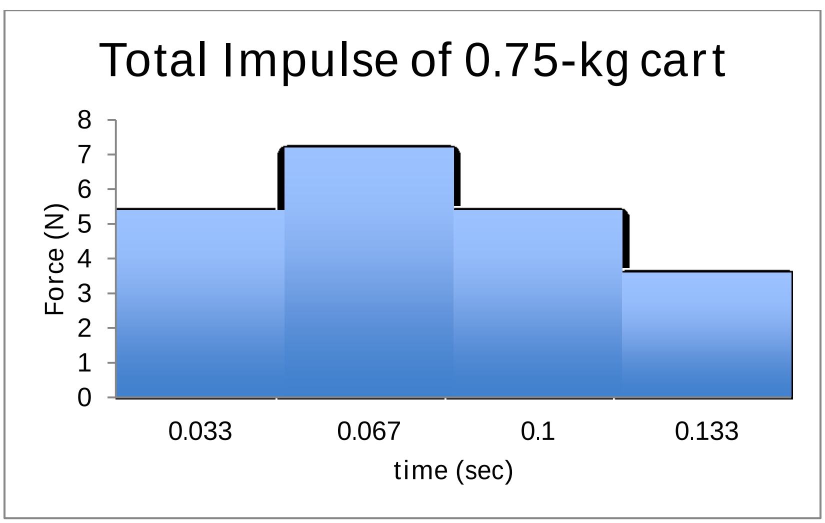
Changing momentum	Mass (kg)	0.25			k-value (N/m)
					360
	v_i (m/s)	-0.42			
	v_f (m/s)	0.42			
					Δt (sec)
	Δp (kg*m/s)	0.21			0.033
Impulse	Δ time (sec)	Δx (m)	Force (N)		Impulse (N*s)
	0.033	0.008		2.88	0.09504
	0.067	0.01		3.6	0.1188
	0.1	0.001		0.36	0.01188
					total J (N*s)
					0.22572



Trial 2

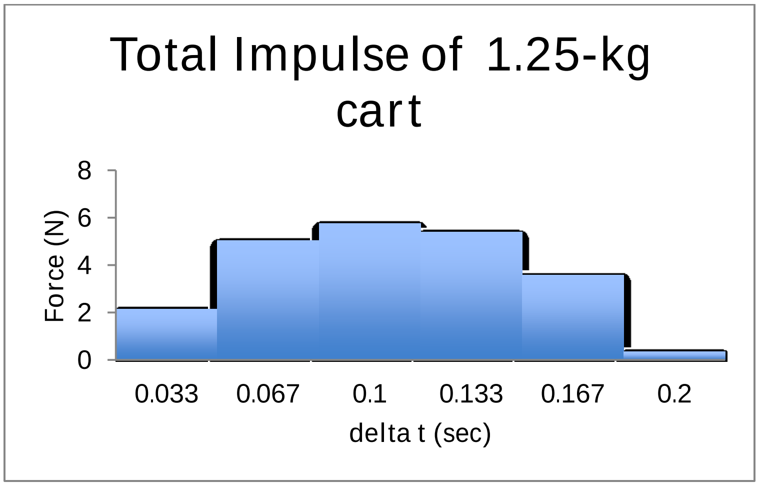
Changing momentum	Mass (kg)	0.75		
	v_i (m/ s)	-0.41		
	v_f (m/ s)	0.45		
	Δ p (kg*m/ s)	0.645		

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



Trial 3

Changing momentum	Mass (kg)	1.25		
	v_i (m/ s)	-0.29		
	v_f (m/ s)	0.29		
	Δ p (kg*m/ s)	0.725		
Impulse	**Δ** time (sec)	**Δ** x (m)	Force (N)	Impulse (N*s)
	0.033	0.006	2.16	0.07128
	0.067	0.014	5.04	0.16632
	0.1	0.016	5.76	0.19008
	0.133	0.015	5.4	0.1782
	0.167	0.01	3.6	0.1188
	0.2	0.001	0.36	0.01188
				total J (N*s)
				0.73656



Possible Discussion Questions:

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

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

Lab 6 Problem 2: Perfectly Inelastic Collisions

Purposes:

1) To use the conservation of momentum and energy in analyzing collisions.
2) To distinguish between nearly elastic and inelastic collisions.

Equipment: track, carts, cart masses, end stop, meter stick, stopwatch

Teaching Tips:

1) Encourage a fast and thorough analysis. Students should be experts by now at finding constant velocity with the carts.
2) You may want to assume an efficiency of 1, just to facilitate the calculations. If you do, make sure to keep the carts' velocities low.
3) Put end stops on the track to minimize damage to the carts.
4) A collision where kinetic energy is conserved is called "elastic." Any other kind of collision is "inelastic."
5) The solution to the prediction equation 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.
6) Do not let a single student monopolize either the computer or the equipment.

Difficulties and Alternative Conceptions:

- Contrary to energy, momentum is a vector.
- Sometimes it is hard for students to understand momentum can be negative when kinetic energy is always positive.
- Momentum is conserved even when kinetic energy is not.
- How does the vector / scalar nature of these quantities explain that?

Prediction and Warm-up Questions:

m_1 = Initially moving mass
m_2 = Initially stationary mass
v_1 = Initial velocity
v' = Final velocity of the system

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

The equations appear in the book, but not many students will have the mathematical stamina to complete the steps for these predictions. Combining the momentum with the kinetic energy equations is the most tedious job they will ever have in physics, and it is far too long to appear on any exam. You may wish to have these predictions finished before the lab and printed on paper to share with your students. Or show them that you have a sufficient number of equations to solve for all the unknowns then stop. These students have not necessarily had calculus. They tend to tire easily of the mathematics, and you need to keep the enthusiasm high.

Possible Discussion Questions:

1) What if the track could be stretched into two dimensions? Do you think momentum would still be conserved? Explain.
2) What are the sources of error in this problem? Is momentum quantitatively conserved within this region of error?

Sample Data and Results:

	m_1 (g)	m_2 (g)	v_1 (cm/ s)	Predicted v' (cm/ s)	Measured v' (cm/ s)
$m_1 = m_2$	503.60	503.12	52.70	26.36	26.50
$m_1 > m_2$	753.80	252.92	43.10	32.27	32.50
$m_1 < m_2$	252.80	753.92	91.00	22.85	23.80

Lab 6 Problem 3: Explosions

Purposes:

1) To help students think critically about momentum conservation by reversing the collision process.
2) To have students think about point masses related to the physical objects.

Equipment: track, carts, cart masses, end stop, meter stick, stopwatch

Things to Remember:

1) Pushing the tip button quickly is the trickiest part of this lab. It is difficult to push the button without impeding the motion of the cart immediately after the button is pushed.
2) Ask students if they are analyzing the carts as point masses and what that means for the simultaneity of their reaching the end stops.
3) There is no need to use the video analysis.

Difficulties and Alternative Conceptions:

- The mathematics behind this problem is most difficult to students. They are required to assimilate a number of different ideas into one elegant product. The carts will not have equal accelerations when they push apart, but once apart, they will each have a constant velocity.

Predictions and Warm-up Questions:

NOTE: The prediction and warm-up questions ask students to treat the carts like point masses. You should ask them how nonzero cart length affects the result.

$$p_{initial} = 0 = p_{final}$$

$$p_{final} = m_A \cdot v_A + m_B \cdot (-v_B) = 0$$

$$d_A = v_A \cdot t; \qquad d_B = v_B \cdot t$$

$$d_A = \frac{m_B \cdot D}{(m_A + m_B)}; \qquad d_B + d_A = D$$

d_A = distance from one end of the track to the end of cart A
m_A, m_B = masses of each cart
D = total length of the track.

Possible Discussion Questions:

1) What happens to our precision when we treat these carts like point masses? Can we be any more precise by taking into account their actual size?
2) Does the velocity of the carts after the explosion overcome the minimum velocity required to see reliable results on the track? (Remember problem 1, Lab I.)

Sample Data and Results:

Mass of cart A: m_A = 252.80g; length of cart A: l_A = 17.10cm
Mass of cart B: m_B = 753.92g; length of cart A: l_A = 17.10cm
Position of the left stopper: 1.90cm
Position of the right stopper: 220.18cm

Predicted attaching position of the two carts: 165.37cm (cart length not considered), 156.86cm (cart length considered)

Measured attaching position of the two carts: 153.80cm

Laboratory 7: Energy

Energy is a useful concept because it is conserved. In fact, it is one of the most useful concepts in physics today. Our qualitative descriptions of energy are only about 150 years old. However, the idea that an object retains some *energetic* quality is ancient.

Problem #1 uses the work-energy theorem to relate kinetic energy and work. Problem #2 illustrates the transfer of energy by only looking at initial and final potential energies.

Prob. #1 Prob. #2

General Teaching Tips:

1) The students should be able to see the simplicity of this model by the end of the lab. They might be asking themselves and you why you didn't just say this in the first place! Conserving energy is often a very simple concept and fairly straightforward to apply and solve. After a semester of what they may think is a complicated subject, they can hopefully see how physicists really do want to work with the simplest system that describes reality.

Things to Remember:

1) Use the Problem Report form (icon on all lab computer desktops) to report equipment problems.
2) 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 lab students should be able to:

1) Develop an understanding of energy and how it applies to different physical situations.
2) Use the conservation of energy to describe the behavior of various systems.
3) Relate work and kinetic energy with the work-energy theorem.
4) Relate initial and final potential energies.

Things to check fifteen minutes before lab:

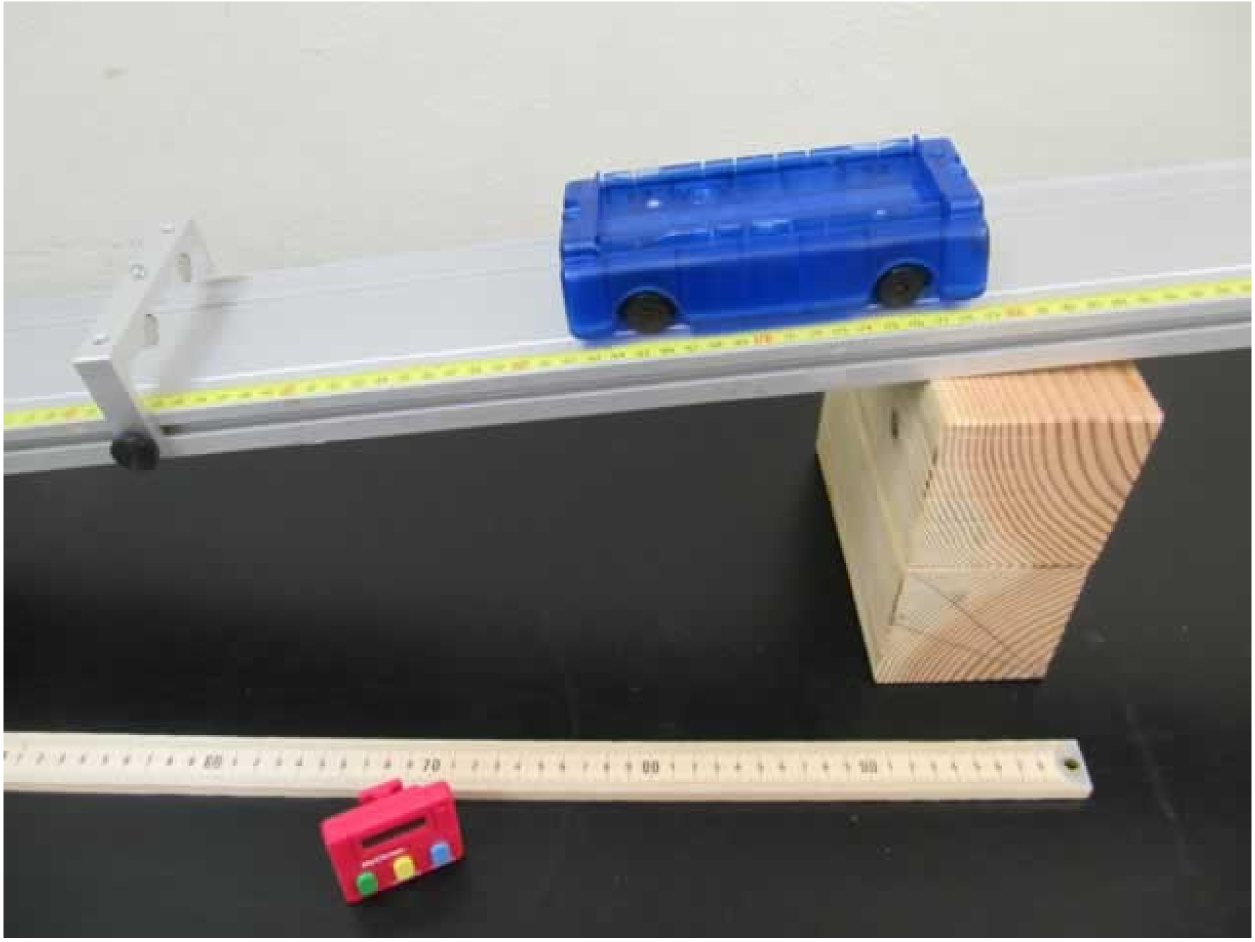
1) By watching several collisions, estimate how much energy is dissipated in a bumper to bumper collision between two carts. This will help you determine if a group has a serious problem understanding the physics.
2) Make sure you know which end of a cart has magnets on it.
3) Too forceful a collision will cause the carts to jump off the track. Play around with different initial velocities so you can guide students to avoid this effect.
4) The Velcro pads sticking to each other are sometimes stronger than the glue attaching the Velcro pads to the carts. When pulling carts apart, pull gently. Try this out.
5) Check out the mass limits for the springs so that you can warn the students how much mass they should be using.

Lab 7 Problem 1: Kinetic Energy and Work

Purposes:

1) To introduce the concepts of kinetic energy and work.
2) To distinguish that the work-energy theorem is a special case of conservation of energy.

Equipment: track, cart, end stop, wood block, meter stick, stopwatch



Teaching Tips:

1) Make sure students catch the carts before they hit the ground.
2) Students are often confused about the qualitative meanings of the terms “work” and “energy”. Look up the definitions given in their text, and be prepared to clarify confusion about them during class.
3) Since the aluminum track is not a smooth transition from the incline to a horizontal surface, the final velocity is two-dimensional. You might remind and/or ask your students about their data analysis (how to get the final velocity from the video.) In some cases the last frame available for data doesn’t correlate with the end of the track, make sure students have a strategy to deal with this.
4) Try out the equipment yourself before the lab. How good are the results if you take data when the cart leaves the incline and rolls onto a horizontal surface, what value for the velocity do you get with the video analysis software?

Difficulties and Alternative Conceptions:

- Students have difficulty knowing when to use the work done by gravity on an object (force “mg” through a change in vertical height h) and the gravitational potential energy of an object, mgh. You will need to help them understand that the work-energy theorem is a special case of conservation of energy, and they only need to include “mgh” in their expression once.

Prediction and Warm-up Questions:

The final kinetic energy of the object will be equal to the work done by gravity on the object (a force that is the gravitational pull of the earth on the object, over a distance h in the direction of the force.) Assume friction is negligible.

$$\frac{1}{2} m v_f^{\,2} = mgh$$

$$v_f = \sqrt{2gh}$$

Possible Discussion Questions:

1) What are the similarities and differences between work and energy?
2) How does the final velocity of the cart (stagecoach) depend on the initial release height? Draw a graph of the relationship.
3) Does the final velocity of the cart depend on the steepness of the incline?

Sample Data:

Car was released so front was 20.1 cm above table and the end of the track was 3.1 cm above table.

h=17cm
v_x predicted is 182 cm/ s

v_x was measured at 179 cm/ s using MotionLab (video was made capturing just the end of track motion allowing for 6 data points.)

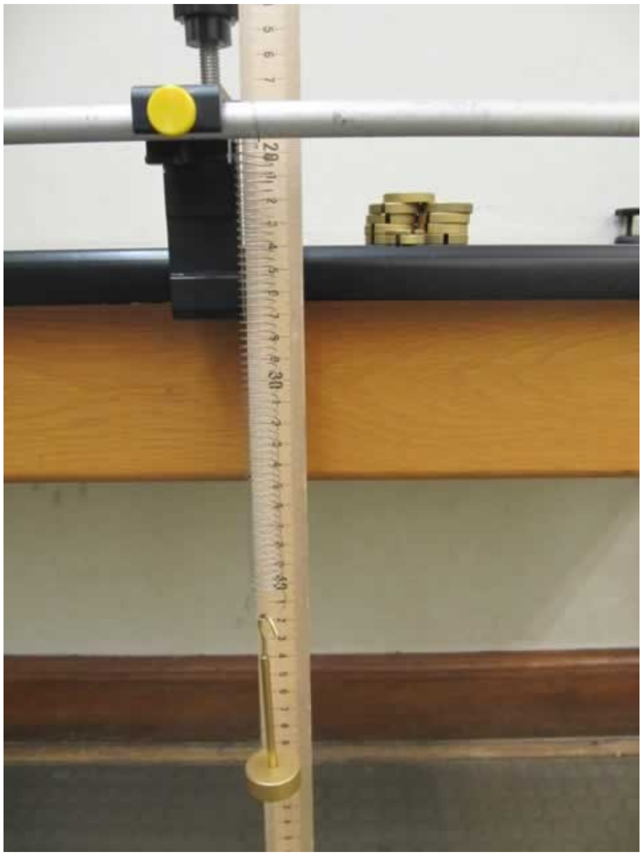
Lab 7 Problem #2: Gravitational Potential Energy and Elastic Potential Energy

Purpose:

1) To show the transfer of energy from two different kinds of potential energy

Equipment:

Meter stick, springs, mass set



Teaching Tips:

- Once the prediction for this lab has been done, the data collection should be straightforward. Have the students take the data for hanging and dropping at the same time.
- Since the mass stops at the bottom, it is very easy to see with just the unaided eye. No need for a video analysis.
- The students can use 5-gram mass increments and still see a difference in the hanging and dropping displacements.
- There is a potential to "think yourself in a circle". It may have something to do with the subtraction of the mass and spring length (yes, it's important and not just an offset issue). Make sure the students are checking the numbers along the way to make sure they are fitting the prediction (i.e. the dropping displacement should be twice the hanging displacement.)

Predictions and Warm Ups:

For Hooke's law:

$$k = \frac{mg}{x}$$

For transfer of energy:

$$k = \frac{2mg}{x}$$

where

$x =$ displacement of the spring from equilibrium

$m =$ mass on the spring

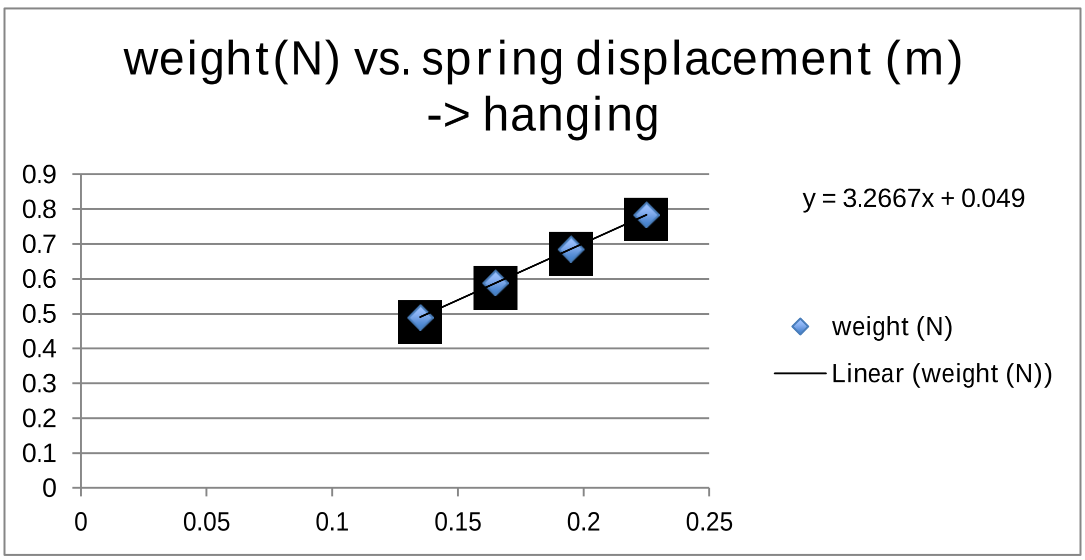
$k =$ spring constant

Data:

Hanging- Hooke's Law

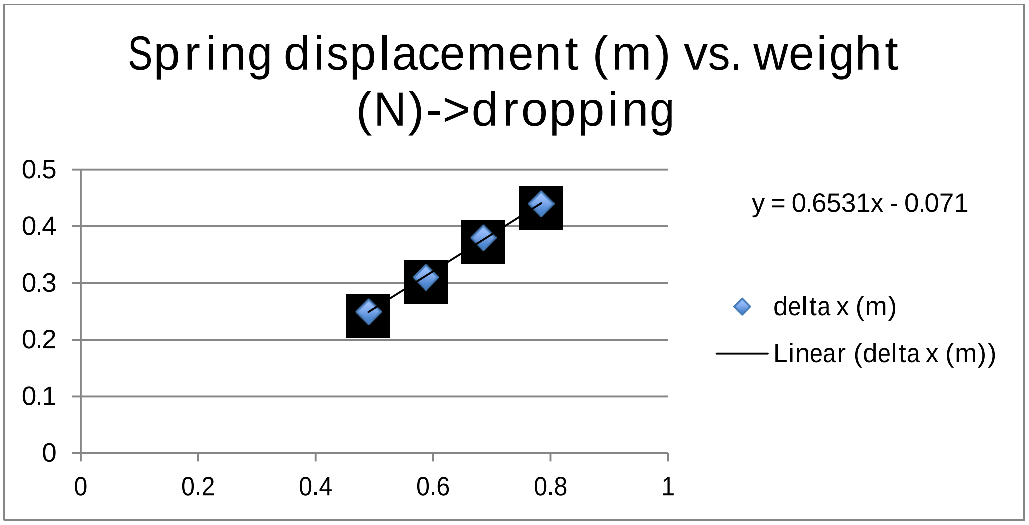
mass (kg)	delta x (m)	weight (N)
0.05	0.135	0.49
0.06	0.165	0.588
0.07	0.195	0.686
0.08	0.225	0.784
0.09		

Delta x's subtracted off the spring length and the mass length



Dropping- transfer of energy

mass (kg)	Weight (N)	delta x (m)
0.05	0.49	0.25
0.06	0.588	0.31
0.07	0.686	0.38
0.08	0.784	0.44
0.09	0.882	



Possible Discussion Questions:

1) What is the relationship between the dropping displacement and hanging displacement?
2) Does it matter if you subtract the length of the mass and spring?

Lab 7 Problem 3: Elastic Collisions

Removed 2012 due to energy

Purposes:

1) To use the conservation of momentum and energy in analyzing collisions.
2) To distinguish between nearly elastic and inelastic collisions.

Equipment: track, carts, cart masses, end stop, meter stick, stopwatch

Teaching Tips:

1) Encourage a fast and thorough analysis. Students should be experts by now at finding constant velocity with the carts.
2) You may want to assume an efficiency of 1, just to facilitate the calculations. If you do, make sure to keep the carts' velocities low.
3) Put bumpers on the end stops to minimize damage to the carts as they go moving into the ends.
4) A collision where kinetic energy is conserved is called "elastic." Any other kind of collision is "inelastic."
5) 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.
6) Do not let a single student monopolize either the computer or the equipment.

Difficulties and Alternative Conceptions:

- Contrary to energy, momentum is a vector.
- Sometimes it is hard for students to understand momentum can be negative when kinetic energy is always positive.
- Momentum is conserved even when kinetic energy is not.
- How does the vector / scalar nature of these quantities explain that?

Prediction and Warm-up Questions:

m_1 = Initially moving mass
m_2 = Initially stationary mass
v_1 = Initial velocity
v' = Final velocity of the system

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} \cdot v_1$$

$$v_2' = \frac{2m_1}{m_1 + m_2} \cdot v_1$$

where v_1' and v_2' are the final velocities of the two carts.

The equations appear in the book, but not many students will have the mathematical stamina to complete the steps for these predictions. Combining the momentum with the kinetic energy equations is the most tedious job they will ever have in physics, and it is far too long to appear on any exam. You may wish to have these predictions finished before the lab and printed on paper to share with your students. Or show them that you have a sufficient number of equations to solve for all the unknowns then stop. These students have not necessarily had calculus. They tend to tire easily of the mathematics, and you need to keep the enthusiasm high.

Possible Discussion Questions:

1) What if the track could be stretched into two dimensions? Do you think momentum would still be conserved? Explain.
2) What are the sources of error in this problem? Is momentum quantitatively conserved within this region of error?

Sample Data and Results:

(bounce apart). Eff from Lab V-3
**Efficiency has been written out of all labs. Assume 1.0 efficiency.

	m_1 (g)	m_2 (g)	v_1 (cm/s)	Eff	Pred v_1' (cm/s)	Meas v_1' (cm/s)	Pred v_2' (cm/s)	Meas v_2' (cm/s)
$m_1 = m_2$	503.60	503.12	61.20	.97	0.97	0.00	60.29	60.30
$m_1 > m_2$	753.80	252.92	62.80	1.00	32.27	32.80	93.97	92.40
$m_1 < m_2$	252.80	753.92	51.70	.98	-25.22	-25.50	25.79	25.70

TA Lab Evaluations
Physics 1101 Lab _________

We strongly encourage you to report issues or problems with any aspect of the lab immediately after completing the lab; please email available information to labhelp@physics.umn.edu. Please try and include topics included below when emailing an evaluation. You may also print out and complete this form, then turn into the lab coordinator's mailbox located in rm. 139 if desired.

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?

____

____

____