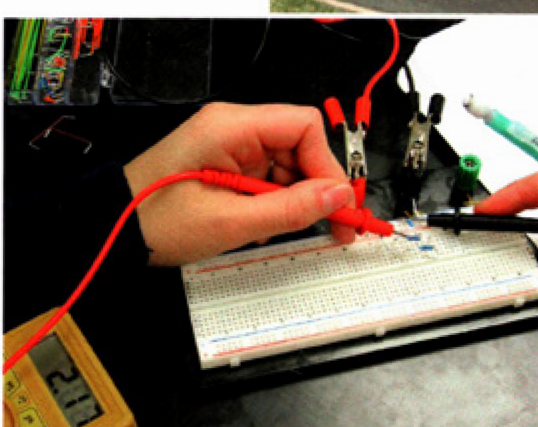
Experiments
for
Introductory Physics and *ASPC*



John D. Mays

Experiments for *INTRODUCTORY PHYSICS* and *ASPC*

Important Notes

The contents of this book are adapted from our book *Favorite Experiments for Physics* and Physical Science. There are some uncorrected page number references, and some references in this book to pages or sections in *Favorite Experiments* that are not included in the present volume.

There are frequent references to Flinn Scientific as an equipment supplier. While Flinn Scientific is a fine supplier for schools, they do not serve home schoolers. For alternate materials sources, see the Materials List beginning on pg. 96.

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The Student Lab Report Handbook
A Guide to Content, Style and Formatting for Effective Science Lab Reports

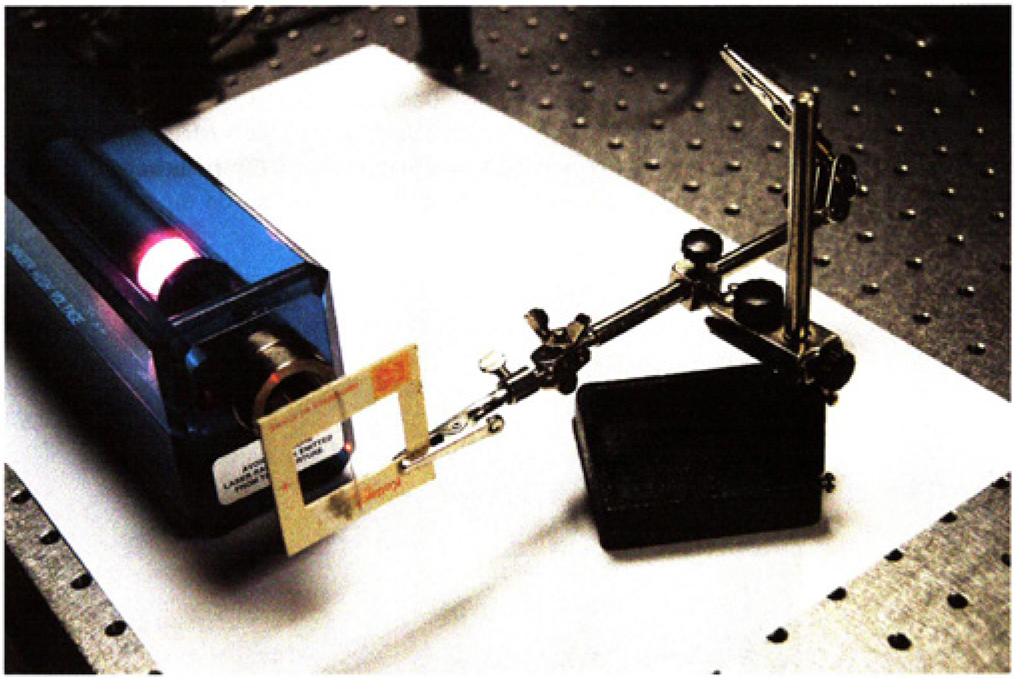
Appreciations and Acknowledgements

As with my previous books, this book would not have been possible without the support, encouragement and collegial collaboration of the faculty at Regents School of Austin. Thanks especially to Chris Corley and Cathy Waldo, who continue faithfully to teach there.

Thanks to Caleb Kyle, who as a 15-year-old student introduced me to blowing up coffee creamer and taught me every single detail of performing that demonstration. Thanks to my old supervising teacher from the 1980s, Sam Saenz, who taught me the art of hunting monkeys.

Thanks to all my family for their continuous encouragement. Special thanks to Jeffrey and Rebekah for their direct support of and contributions to this project. And thanks to my brother-in-law Ray Arneson, who gave me the plywood Magic Belt hook.

Finally, thanks to good friend and gentleman scientist Dr. Chris Mack. To produce good science books one must never tire of infinitessimal improvements in the details. In this regard, Chris is just as much a perfectionist as I am, and never lets me off the hook.



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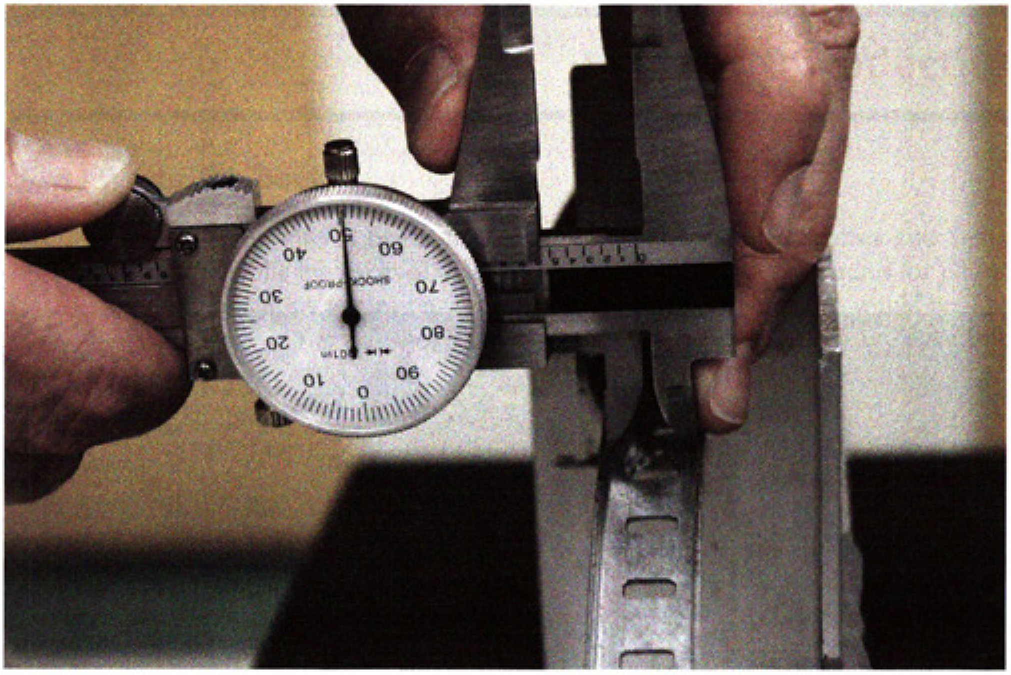

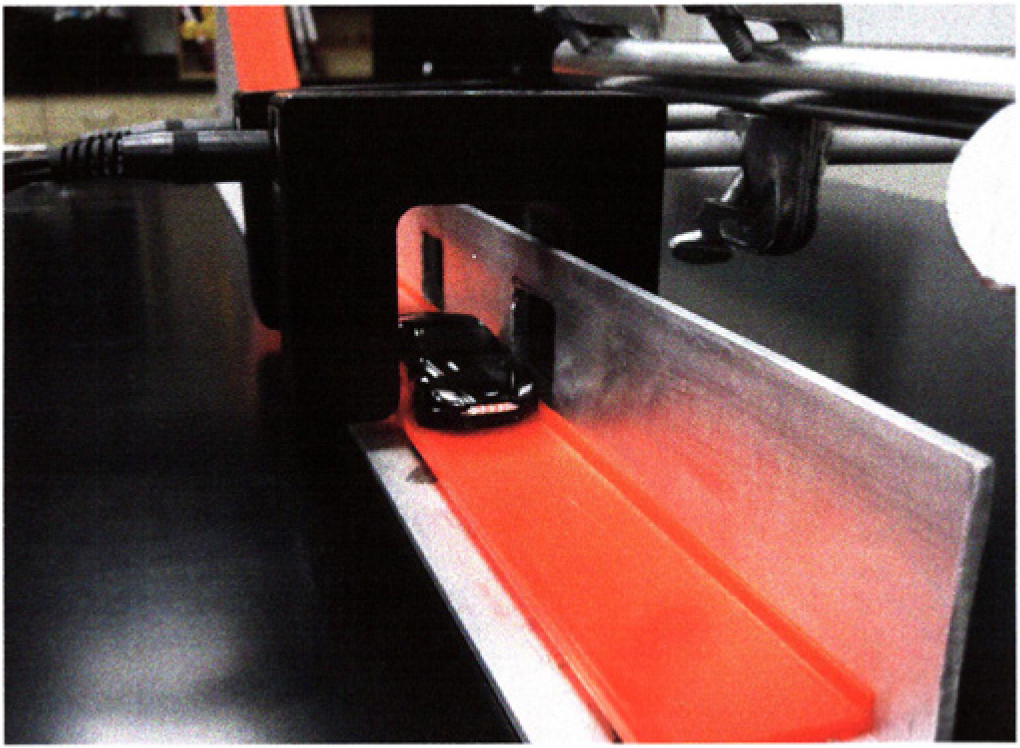

Introduction

Why I Wrote This Book

Back in the 1980s when I began teaching ninth grade Physical Science and Senior Physics, I was at a public high school that had not invested much in apparatus for physics labs. So as I began planning my lessons for that year I did what anyone else would do. I got the "Lab Manuals" for our texts, studied them to learn what equipment was required for all the experiments, wrote up a big purchase order and bought all of it. You probably know what kind of equipment I am talking about—little carts; mass sets; ticker-tape timers; ramps and little wooden boxes for fooling with friction; spring scales; a balance beam for demonstrating torque; DC circuit kits; etc., etc.

I studied the teacher's guides, wrote up lesson plans, and enthusiastically led the students in their lab activities like I was Delacroix's *Liberty Leading the People*. My doubts about the whole process began when I tried to explain how to use the space between the dots on the timer tape to determine the speed of the cart at different times. What a cumbersome way to measure velocities, I thought. In a decade when everything was going digital and many students already had computers at home, the technology seemed crude and the unwieldy strips of paper were a pain. Moreover, it was often the case (and still is) that the apparatus either didn't work or the accuracy was low. The torque balance beam demo with a meter stick is so finicky it is frustrating to the teacher and unconvincing to the students. The wheels tend to come off of the little carts. The DC circuit kits look like they belong in an elementary school classroom.

The mathematical connection between the spacing of the dots and what we were studying was there, of course, but even after careful review with the students many of them were clearly thinking, "We do what? With what? Okay, whatever you say." Not a good way to build interest in what I felt should be everyone's favorite subject.

An effective classroom is not a place where students mindlessly go through the motions of tasks they do not understand in order to perform an "experiment" that does not interest them.

So I began using my imagination to dream up better ways to engage students in lab activities that would provide them with a more meaningful encounter with the basic principles of physics. My motivation was to develop experiments and demonstrations that would be academically solid, inexpensive and interesting.

The activities in this book are the results of those years trying things out and improving my home-made apparatus to increase the reliability and accuracy of the results. These experiments and teacher demonstrations are the ones I presently do in my own classes, the little carts and friction boxes now gathering dust in a closet.

Most of these experiments can be performed very inexpensively. In my descriptions I indicate how to do the experiment with little investment, making the experiments accessible to schools and homes with limited funds. Over the years I have enhanced some of these experiments with digital electronics for data collection. This makes the experiment more interesting to the students, who are surrounded with digital electronics and tend to find anything else uninteresting. The electronics also increase accuracy significantly, improving results and making the analysis more satisfying. But my experience has shown that the simple act of doing an experiment outside with a pickup truck is so exciting for the students that they will love it whether you collect force data with fancy digital equipment or with lowly bathroom scales purchased from a discount store, as I did for many years. If budgetary constraints are an issue for you, start doing the experiments without the fancy digital equipment. You can modify the experiment and add the electronics over time as funds become available.

I know there are a lot of books out there with ideas for science experiments. But the emphasis in this book is on experiments that are captivating, are low cost (at least initially), provide solid opportunities to do physics (and a little chemistry), and use equipment that is either already familiar or worth knowing about. I hope some of these experiments will enhance your own classes.

How Many Labs to Do

As a public school teacher in Texas in the 1980s I was required to make 40% of my class time laboratory-based. Even as a young man just beginning a teaching career I knew this was an insane standard. For starters, once students are in high school their science studies need to be academically rigorous. If a student finishes a course in physics, he or she ought to know the basic principles of physics and be able to solve problems. But three days per week to study the theory is not adequate time for students to master the basic calculations of high school physics.

Reinforcing this problem is the fact that typical "lab manuals" include 25 or 30 different experiments, implying that teachers need to spend a day or two every week running labs and that students need to be filling out report sheets every week. Such an environment, requiring students to race through lab activities and crank out weekly fill-in-the-blank reports will almost certainly be superficial, feeding what I call the *Cram-Pass-Forget cycle*. Students cram for tests, pass them, and then forget most of what the teacher wanted them to learn. I am opposed to superficiality in principle and deeply concerned about this deplorable trend in science education in particular. Students should learn fewer topics but learn them deeply through extended class discussion, in-depth problem assignments, and report writing that is engaging. The result will be deeper comprehension and retention of fundamentals. This in turn will allow students more easily to grasp and master more advanced topics in future studies.

These considerations suggest we should be looking at more like five to six full experiments with lab reports each year for high school science classes.

The Importance of Real Lab Reports

Writing lab reports is a crucial element of the science laboratory experience. To equip your students with the information they need to prepare high quality reports, I commend to you my resource for students, *The Student Lab Report Handbook*.[1] This volume contains all the information students need to use lab journals and prepare excellent lab reports, and can be considered a companion volume to this book. In the preface to *The Student Lab Report Handbook* I make the case for requiring students to produce their own typed lab reports

1 *The Student Lab Report Handbook*, by John D. Mays (2009). Available from Novare Science and Math at novarescienceandmath.com.

from scratch, rather than using pre-printed forms in a lab manual. Writing such a report is a significant undertaking and requires a lot more time than students can afford to give every week. Thus, it is important to select lab activities very carefully so that they support the goal of deep engagement. Experiments have to hit on key topics, they have to be spaced out so there is adequate time for report writing, and they have to have enough complexity to support deeper analysis. In physics this deeper analysis usually involves predicting results from theory, and comparing experimental results to predictions with properly designed graphs.

In the Student Instructions for most of the experiments in this book there are remarks addressing specific issues pertaining to the lab report for the experiment. These comments are based on the assumption that students are asked to prepare reports in accordance with the requirements presented in *The Student Lab Report Handbook*.

Do We Need This Much Detail?

After reading some of my experiment descriptions, you may be tempted to accuse me of being pedantic to a fault. So much detail! How can anyone remember all of these little details?! This guy is nuts! Well, this is what the real world of science is like—excruciating, fastidious, mind-numbing attention to detail, and to the elimination of every conceivable source of error. In every lab activity you perform, impress upon your students the paramount importance of attending to detail and employing painstaking care. In so doing you are teaching them part of the ethos of good experimental science.

Teacher Background

In this book the theoretical background for the experiments is quite abbreviated. Teachers who are new to teaching physics or who would like to read the theory behind the experiments in full detail should refer to a good text on the subject. For the experiments and demonstrations in the Physical Science section, full descriptions of the theory and the calculations involved may be found in my texts *Accelerated Studies in Physics and Chemistry* and *Introductory Physics*.

Accuracy, Precision, Significant Digits, Units of Measure, etc.

I assume many of my readers already know the difference between accuracy and precision, and how to deal with units of measure. However, it is also the case that teachers without a strong background in physics are sometimes recruited to teach it. Most of the experiments in this book involve predicting a physical quantity, measuring the quantity in the experiment, and comparing the predicted value to the experimental value. This process always involves measurements and computations, and these in turn always involve units of measure and everything else that goes with making measurements.

For those readers who may not be familiar with the details of these issues, who would appreciate some advice on what to cover in class, or who would like a short tutorial on the units involved in the experiments in this book, I have included an Appendix that contains a primer on measurement.

Learning Objectives for a Secondary Science Laboratory Program

There are many learning objectives to consider when organizing a lab program for middle and high school students. Most of these objectives are realized over a period of several years, as students go through several different science courses and engage in a number of experiments in each course.

The general objectives I have identified and seek to address in the experiments in this book are listed in the table below. The goal is that after having completed the secondary course of study at a school, students will be competent in each of the objectives listed. The objectives listed in the table are addressed by nearly every experiment in this book.

General Learning Objectives for a Secondary Science Laboratory Program	
After completing the program of laboratory exercises in the secondary program, students will be able to demonstrate competence in each of the following tasks:	
1	State and follow standard laboratory safety practices.
2	Correctly identify and use standard laboratory apparatus.
3	Use proper care in setting up apparatus and handling materials to maintain a safe environment, protect equipment and maximize accuracy in results.
4	Describe and follow the proper methods for making measurements with common instruments. This includes identifying the types of errors that can introduce inaccuracies in measurements and describing how to avoid them.
5	State the role of precision in taking measurements, and relate this to the significant digits in a measurement.
6	Apply the scientific method to conducting experiments and to writing reports.
7	Apply appropriate logic to conducting experiments and to writing reports.
8	Maintain a proper lab journal.
9	Clearly explain the theoretical background behind an experiment using quantitative analysis where appropriate.
10	Use quantitative predictions from scientific theory to form testable hypotheses.
11	Clearly and efficiently describe a scientific procedure and the results and discoveries that followed.
12	Use appropriate care in experimental procedures and data collection.
13	Present calculations and data in a clear, organized fashion such that others can verify calculations or check results. This includes development of tables and graphs using standard scientific units and formatting.
14	Apply quantitative analysis to experimental data as appropriate.
15	Apply qualitative analysis to experimental results as appropriate.
16	Estimate uncertainty in measurements.
17	Apply cogent reasoning to analysis and discussion of experimental results. This includes reasonable identification of the factors that contributed to the difference between predicted and measured results (aka, "experimental error").
18	Use computer tools to take data, graph data, manipulate data and develop reports.
19	Use clear, concise, and accurate language in a technical style in scientific reports.

General Learning Objectives for a Secondary Science Laboratory Program	
20	Explore the uses and limitations of unfamiliar scientific equipment.
21	Cooperate with team members successfully to accomplish each of the above objectives.

In addition to these general objectives, each experiment has one or more unique features that suggest specific objectives that apply to that experiment. These specific objectives are listed at the beginning of each experiment.

Student Instructions for Experiments

Student instructions are included at the end of each of the 11 experiments. These instructions may be reproduced and distributed to students. Alternatively, PDF files of the student instructions are available as free downloads from our website, novarescienceandmath.com. These may be downloaded, reproduced and distributed to students. Simply go to the Free Resources tab on the website and enter the pass code "novarefavexp."

A Note About Experimental Error

One of the conventional calculations in high school science labs is the so-called "experimental error." This experimental error is typically defined as the difference between the predicted value and the experimental value, expressed as a percentage of the predicted value, or

$$\text{experimental error} = \frac{|\text{predicted value} - \text{experimental value}|}{\text{predicted value}} \times 100\%$$

From the perspective of the average high school student, this use of "experimental error" makes perfect sense. After all, student are studying well-established theories and the goal of the experiment is to learn about the theory, not to validate or refute it. In the world of science, however, experiments are the golden standard by which theories are judged. When there is a mismatch between theory and experiment, it is often the theory that is found wanting. That is how science advances.

In my early books, such as *The Student Lab Report Handbook*, I used this same terminology ("experimental error") to express the difference between prediction and result. Over the years, however, research and discussions with practicing scientists have led me to the conclusion that this terminology is misguided. Used in this way the term *error* implies that the theory is *correct* and that the error in the experiment may be summarized by this difference equation. However, the difference between prediction and experimental result may not be caused by deficiencies in the experiment. In more general scientific practice the theory may *not* be correct. Thus, in secondary classrooms it is better to reserve the term *error* for discussions about lack of accuracy in specific measurements, when the measurement is known to contain or is suspected of containing error (that is, differing from the true value, see Appendix). Referring to the overall difference between prediction and experimental result as "experimental error" is a bad habit to get into.

Consider this case: an experimental measurement of velocity produces a value that is consistently less than the predicted value. Most likely this is because the predictions did not take air resistance into account. Is this an experimental error? It is more correct to say that the theory is inaccurate because we made the unrealistic assumption that there would be no air resistance. Such causes of differences between predictions and measurements are quite common, and it is great if the future scientists in your class can understand that this is not an error in the experiment.

As a result of these considerations, beginning with this book I am adopting a different convention. Henceforth I will use the phrase "prediction-result difference ratio" to describe the value computed by the above equation. When quantitative results can be compared to quantitative predictions, students should compute the difference ratio as

$$\text{prediction-result difference ratio} = \frac{|\text{predicted value} - \text{experimental value}|}{\text{predicted value}} \times 100\%$$

In the Discussion section of their lab reports, students should state the value(s) of the prediction-result difference ratio for their experiment. After doing so, much of their subsequent analysis of the experimental result will consist in attempting to identify the reasons for this difference. Students may use the possibility of *errors* in different measurements, along with other factors such as lurking variables or insufficiently elegant experimental methods, in their attempts to account for the prediction-result difference. Being able to explain the prediction-result difference for an experiment is one of the most important jobs of the scientist—and the science student.

Experiments

It is common these days for middle school students to take a course entitled "Physical Science." Although some of these experiments could be adapted for use in middle school, the six experiments in this section were developed for *high school* courses of introductory physics and chemistry for ninth grade students. The math involved is generally beyond what middle school students are prepared for.

The sequence of experiments is compatible with a standard curriculum in high school physical science, which includes introductory physics and chemistry. These same six experiments are incorporated into my text *Accelerated Studies in Physics and Chemistry*, designed for accelerated or honors-level high school freshmen. Five of these experiments (all but the Solubility Lab) are also incorporated into my text *Introductory Physics*, designed for grade-level high school freshmen.

The real purpose of the first experiment, The Pendulum Lab, is to introduce students to some important experimental methods. The physics of the pendulum is incidental. Since the Pendulum Lab is conceptually simple and there are no graphs to prepare in the report, students can concentrate on learning standard report content and formatting without the complication of preparing graphs. Graphs are added in the second experiment, The Soul of Motion Lab. By holding off graphing until the second report, students can learn the details of report writing in phases during the fall semester, and then polish these skills during subsequent reports. The goal is for students to become proficient at report writing during the freshman year. Then when they encounter more advanced material they can focus their attention on the scientific content of the experiments instead of being distracted by the task of synthesizing the report.

Finally, please see the Introduction (page 6-7) or the Appendix (page 249) for information about my use of the phrase, "prediction-result difference ratio."

Experiment 1 The Pendulum Lab

Learning Objectives

Features in this experiment support the following learning objectives:

1. General objectives for laboratory experiments (see page 4).
2. Collect data in an organized fashion.
3. Control variables in an experiment.
4. Present data in tables.
5. Develop a complete lab report from scratch.

The real purpose of the fun little Pendulum Lab is to introduce students to experimental methods, including data collection, using a lab journal, manipulating variables one at a time, setting up tables, and report writing. The physics of the pendulum is incidental. For this reason, this is an excellent experiment to perform within the first two weeks of the school year, independent of the topic under study in the curriculum.

Materials for this experiment cost only a few dollars. The experiment is simple to perform and can be conducted in 45 minutes. Students are fascinated by the apparent simplicity of the problem, and the answer to it, which they invariably fail to guess correctly in advance. They are intrigued that such a simple set up can return such a non-intuitive result.

Materials Required (per lab team, four students max per team)

1. nylon string, 1 meter
2. large paper clip
3. large steel washers (3)
4. meter stick, broom handle, yardstick, or similar item
5. duct tape or masking tape
6. clock with sweep second hand (the classroom wall clock works fine) or stop watch

Experimental Purpose

Determine the explanatory variables that affect the period of a pendulum.

Overview

Using simple materials, each student team makes a pendulum and tests it to see how many periods (full swings over and back) the pendulum will complete in a 10-second time interval. Students adjust the variables (the starting angle, the weight, and the length of the string) independently, conducting three separate trials for each configuration. Students record the data in their lab journals.[1] When all trials have been completed, students analyze their data to determine which variables affected the period in their trials. When trials are conducted carefully the data should clearly show that only the length of the string affects the period.

The pendulum is made by unfolding a large paper clip to use as a hook. The paper clip is attached to the end of a string. The other end of the string is tied to the end of a meter stick (or similar item) and the meter stick is placed on a table top so the pendulum hangs over the edge and swings freely. The meter stick is held in place on the table top by masking tape or duct tape. Large washers are hooked onto the paper clip and serve as the weights.

Pre-Lab Discussion

Cover the following items with the entire class the day before the lab exercise.

1. Define the period of an oscillating system and its unit of measure. In any oscillating system the period is the length of time required for the system to complete one full cycle of the oscillation. Commonly the lower-case Greek letter tau, τ, is used to denote the period. The period is measured in seconds (s).
2. Ask students to suggest the possibilities for explanatory variables that could affect the period of a pendulum. In terms of the "scientific method," this discussion corresponds to the "state the problem" step. There are three mechanical possibilities inherent in the pendulum itself: the weight, the length of the string, and the starting angle from which the pendulum is released. Guide the discussion until these three possible explanatory variables are identified. Confirm that there are other marginal factors that may affect the period such as the air or the rotation of the earth, but that these variables will not be considered in this experiment.
3. Give the teams a few minutes to discuss the three possible explanatory variables as a team. Ask them to consider their own experience and practical mechanical knowledge and form a team hypothesis about which one(s) will affect the period. The teams' discussions will constitute the "research" step of the scientific method. Instruct the students to document their team's hypothesis in their lab journals.
4. Explain the fact that since a single period of a pendulum would be too short to measure accurately, we will instead allow the pendulum to swing freely for 10 seconds while the number of complete swings is counted. (One "swing" is all the way over and all the way back to the starting position.) This is much easier to measure and gives us the same information as the period itself. (In fact, we could compute the period from the 10-second swing data by dividing 10 seconds by the number of swings counted.) The team member counting the swings should closely observe the position of the pendulum and estimate the total number of swings in one 10-second interval to the nearest 1/4 swing. So the data collected for each trial

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1 In addition to data there are many other items that students need to record in their lab journals. For complete details on the use of lab journals, please see *The Student Lab Report Handbook*, available from Novare Science and Math at novarescienceandmath.com.

during the experiment consists of the number of complete swings, plus any partial swing rounded to the nearest 1/4 swing, completed by the pendulum in ten seconds.

5. Review the need to test each explanatory variable independently, and present how this can be managed for the three variables being tested here. Since this is probably the first time students have conducted an experiment with three variables to test, the teacher needs to show students how to do this and how to set up appropriate tables for collecting data. These matters can be presented as follows:

    a. Of the three variables under test, the angle is easiest to change. So it makes sense to set up each configuration of the pendulum and test it at two different starting angles.

    b. Students will first construct the pendulum with the longest possible string (full length) and the heaviest weight (all three washers). For this configuration the string needs to be 75 to 100 cm long. Students will test this pendulum at each of two different angles. The small angle will be when the pendulum is pulled back about 10 degrees from vertical to be released. The angle can be estimated by one of the team members. Three trials will be conducted at this angle to assure that the data are consistent.

    c. The large angle will be about 40 degrees from vertical. As before, three trials must be conducted.

    d. Students must record all the data for these trials in their lab journals in a table like the one below. In each cell in the table students record the number of swings the pendulum completed in the ten second timing interval.

Number of swings completed by long string, heavy weight pendulum		
trial	small starting angle	large starting angle
1		
2		
3		

    e. Since changing the weight on the pendulum can be done quickly, it makes sense to change this variable next. So after completing the six long string, heavy weight trials, students will take off two of the washers, keep every thing else the same, make another table for "long string, light weight" data and conduct the trials, using small and large angles (three trials each) as before.

    f. After completing the two tables of long string trials, students will shorten the string down to about 25 cm long. Then they conduct trials to fill up two more tables (one for heavy weight, one for light weight) as before. Students will have four tables of data in all, and must conduct 24 separate trials.

6. To assure the best accuracy, encourage students to check that the meter stick is steady while the pendulum is swinging. Tell them also to make sure that the large angle is 3-4 times as large as the small angle, without going over 45 degrees or so from vertical, and that the long string is 3-4 times as long as the short string. The general rule is that for each of the three variables under test, the large value of the

variable should be at least three times the small value. This degree of variation will assure that if the variable does affect the period the data will clearly show it.

7. Teams should divide up the tasks for conducting the trials. One team member watches the clock and gives the signals to start and stop the trials. Another team member pulls back and releases the pendulum at the correct angle on the signal, making sure to start the pendulum from a reliably consistent position. A third team member carefully counts the swings until the stop signal is given, calling the number of swings to the nearest quarter swing. A fourth team member can record the data in his or her lab journal and share it with the other team members after the data collection is complete.

Scoring the Student Lab Reports

At the school where I developed this experiment we introduce students to the full requirements of report writing in ninth grade. During the rest of the fall term and on into the spring term students are expected to improve the quality of their reports with each new attempt. Our goal is that by the time they finish their freshman year the students are very familiar with standard report content, style and formatting, and have developed solid descriptive and analytical skills. Thus prepared, they enter their tenth grade science courses equipped to engage their science studies at an even deeper level, being able to focus more on the science and less on learning how to write lab reports.

This being the case, this is the students' first report, the first in a series of reports designed to train them in the art of writing good technical papers. The goal for the first one is that they are able to get the major building blocks in place. There is a lot to learn, and writing good reports entails many details, including a lot of specific formatting requirements. My policy for this first report is that any student who reads through the basic chapters of *The Student Lab Report Handbook*[2] and makes a good faith effort to put together a good report that includes the essential ingredients with serviceable English writing will receive at least a B. I expect on this first report that the students will miss many of the formatting requirements described in *The Handbook*. This is not a problem. Writing good reports takes practice, so I gradually raise the grading standard with each new report throughout the year.[3]

Student Instructions

A set of instructions you may reproduce and give to students begins after the illustrations. This set of instructions is taken from my freshman science texts *Introductory Physics* and *Accelerated Studies in Physics and Chemistry*.

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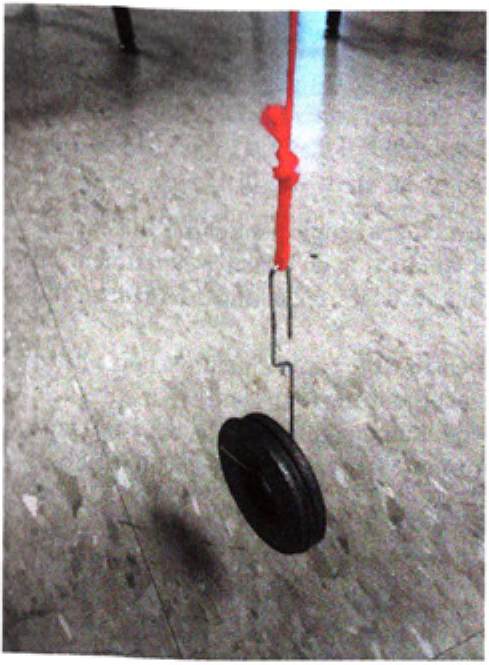
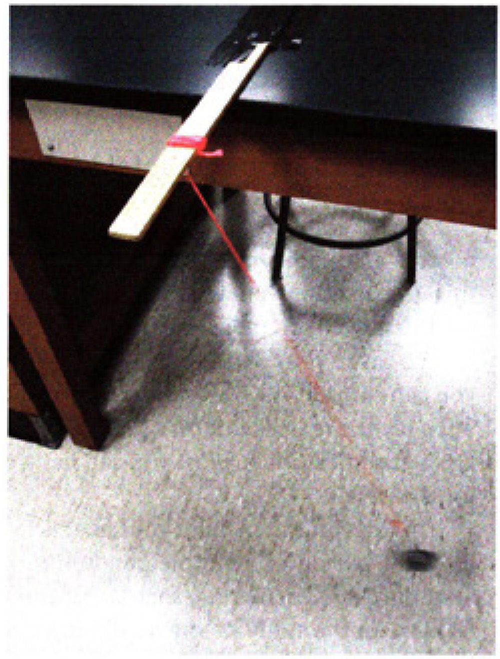
2 See the Introduction for details.

3 I presented a grading rubric for high school lab reports in my 2010 book, *Teaching Science so that Students Learn Science.*



String, hook and weights ready to go.



The pendulum in action.

Student Instructions

The Pendulum Lab

Variables and Experimental Methods

We are going to conduct an investigation involving a simple pendulum. This experiment is an opportunity for you to learn about conducting an effective experiment. In this investigation you will learn about controlling variables, collecting careful data, and organizing data in tables in your lab journal.

To make your pendulum, your team will bend a large paper clip into a hook. Then you can connect the hook to a string, and connect the string to the end of a meter stick. Then lay the meter stick on a table with the pendulum hanging over the edge and tape the meter stick down. Now you can hang one or more large metal washers on the hook for the weight.

In this fun experiment your goal is to identify the explanatory variables that influence the period of a simple pendulum. A pendulum is an example of a mechanical system that is *oscillating*, that is, repeatedly "going back and forth" in some regular fashion. In the study of any oscillating system an important parameter is the *period* of the oscillation. The period is the length of time (in seconds) required for the system to complete one full cycle of its oscillation. In this experiment the period of the pendulum is the response variable you will be monitoring. (Actually, for convenience you will be monitoring a slightly different variable, closely related to the period.) After thinking about the possibilities and forming your team hypothesis, you will construct your own simple pendulum from string and some weights and conduct tests on it to determine which variables actually do affect its period and which ones do not.

In class you will explore the possibilities for variables that may affect the pendulum's period. Within the pendulum system itself there are three candidates, and your instructor will lead the discussion until the class has identified them. (We will ignore factors such as air friction and the earth's rotation in this experiment. Just stick to the obvious variables that clearly apply to the problem at hand.)

Then as a team you will continue the work by discussing the problem for a few minutes with your teammates. In this team discussion you will form your own team hypothesis stating which variables you think will affect the period. To form this hypothesis you will not actually do any new research or tests. Just use what you know from your own experience to make your best guess.

The central challenge for this experiment will be to devise an experimental method that tests only one explanatory variable at a time. Your instructor will help you work this out, but the basic idea is to set up the pendulum so that two variables are held constant while you test the system with large and small values of the third variable to see if this change affects the period. You will have to test all combinations of holding two variables constant while manipulating the third one. All experimental results must be entered in tables in your lab journal. Recording the data for the different trials will require several separate tables. For each experimental setup you should time the pendulum three times and record the result in your lab journal. Repeating the trials this way will enable you to verify that you have good, consistent data. To make sure you can tell definitively that a given variable is affecting the period, you should *make the large value of the variable at least three times the small value in your trials.*

Here is bit of advice about how to measure the period of your pendulum. The period of your pendulum is likely to be quite short, only one or two seconds, so measuring it directly with accuracy would be difficult. Here is an easy solution: Assign one team member to hold the pendulum and release it on a signal. Assign another team member to count the number of swings the pendulum has completed, and another member as a timer to watch the second hand on a clock. When the timer announces "GO" the person holding the pendulum releases it, and the swing counter starts counting. After exactly 10.0 seconds the timer announces "STOP" and the swing counter states the number of swings that have been completed. Record this value in a table in your lab journal. If you have four team members, the fourth person can be responsible for recording the data during the experiment. After the experiment the data writer can read off the data to the other team members so they can enter the data in their journals.

This method of counting the number of swings in 10 seconds does not give a direct measurement of the period, but you can see that your swing count will work just as well for solving the problem posed by this experiment, and is a lot easier to measure than the period itself.

One more thing on measuring your swing count: Your swing counter should state the number of swings completed to the nearest 1/4 swing. When the pendulum is straight down, it has either completed 1/4 swing or 3/4 swing. When it stops to reverse course on the side opposite from where it was released, it has completed 1/2 swing.

When you have finished taking data, review the data together as a team. If you did the experiment carefully your data should clearly indicate which potential explanatory variables affected the period of the pendulum and which ones did not. If your swing counts for different trials of the same setup are not consistent, then something was wrong with your method. Your team should repeat the experiment with greater care so that your swing counts for each different experimental setup are consistent.

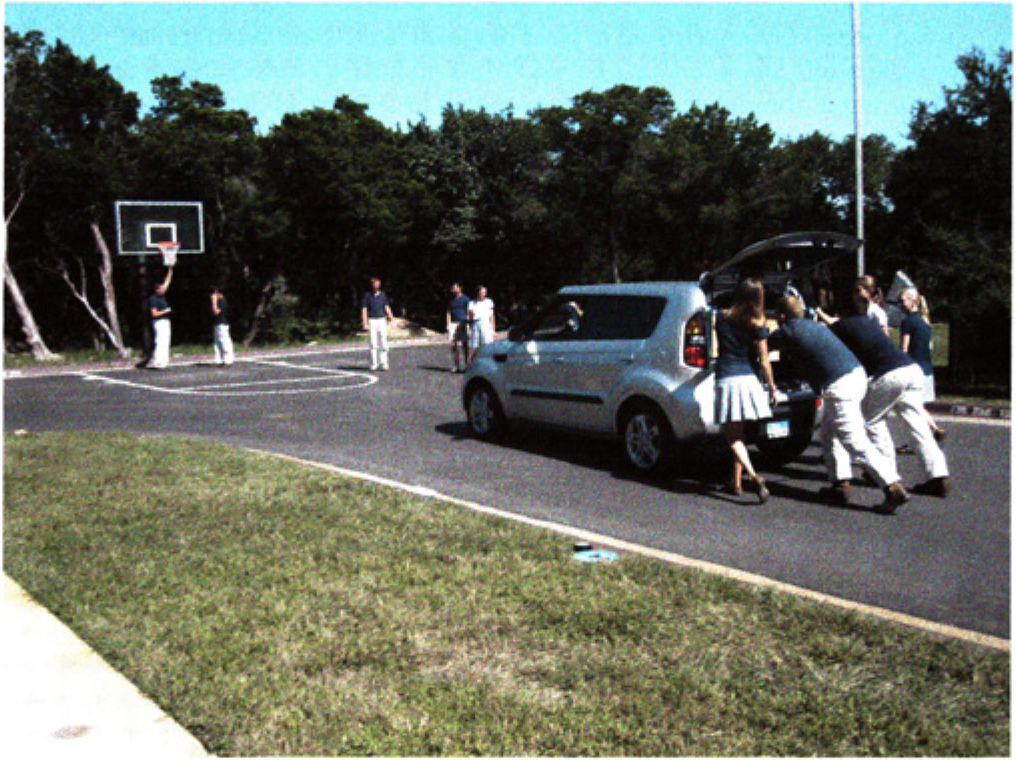
Discuss your results with your team members and reach a consensus about the meaning of your data. You should expect to spend at least four hours writing, editing and formatting your report. Lab reports will count a significant percentage of your science course grades throughout high school, so you should invest the time now to learn how to prepare a quality report.

Your goal for this report is to begin learning how to write lab reports that meet all of the requirements outlined in *The Student Lab Report Handbook*. One of our major goals for this year is to learn what these requirements are and become proficient at generating solid reports. Nearly all scientific reports involve reporting data, and a key part of this first report is your data tables, which should all be properly labeled and titled.

After completing the experiment all of the information you will need to write the report should be in your lab journal. If you properly journaled the lab exercise you will have all of the data, your hypothesis, the materials list, your team members' names, the procedural details, and everything else you need to write the report. Your report must be typed, and will probably be around two or three pages long. You should format the report as shown in the examples in *The Student Lab Report Handbook*, including major section headings and section content.

Here are a few guidelines to help you get started with your report:

1. There is only a small bit of theory to cover in the Background section, namely, to describe what a pendulum and its period are. You should also explain why we are using the number of swings completed in 10 seconds in our work in place of the actual period. As stated in *The Student Lab Report Handbook*, the Background section must include a brief overview of your experimental method and your team's hypothesis.
2. Begin your Discussion section by describing your data and considering how they relate to your hypothesis. In this experiment we are not making quantitative predictions, so there will be no calculations to perform for the discussion. We are simply seeking to discover which variables affect the period of a pendulum, and which do not. Your goal in the Discussion section is to identify what your data say and relate that to your reader.
    a. What variables did you manipulate to determine whether they had any effect on the period of the pendulum?
    b. What did you find? Which ones did affect the period? How do the data show this?
    c. Were you surprised by what you found?
3. If you would like to produce a really outstanding report, consider exploring the following questions in your discussion:
    a. Many clocks use pendulums to regulate their speed. What is it about pendulums that makes them good for this?
    b. How would this work in an actual clock?



Experiment 2 The Soul of Motion Lab

Learning Objectives

Features in this experiment support the following learning objectives:

1. General objectives for laboratory experiments (see page 4).
2. Present theoretical predictions and experimental results on the same set of axes in a graph.
3. Use theory to make quantitative predictions of experimental results.
4. Use proper formatting and presentation for graphs in reports.
5. Explore and learn how to use unfamiliar scientific equipment.

For over a decade my freshman students called this investigation of Newton's Second Law of Motion the Pick-up Truck Lab. For many of them, especially the boys who love exhibiting their strength while pushing my Ford F-150 pick-up truck around in the school parking lot, it is probably the most enjoyable experiment in the entire year. For getting the students out of the classroom and allowing them to be physically active, this is about as good as it gets in a physics class!

I got the idea for this experiment from a journal article I read by another physics teacher over 20 years ago.[1] In this experiment students have their first chance to use theory to predict the outcome of an experiment and compare their experimental results to their predictions. If done well the difference between the predictions and the results can turn out surprisingly low, significantly less than 5%. The subsequent report entails learning how to prepare graphs showing both predicted and experimental values.

As I write this I have just replaced my old truck with a new KIA Soul and have modified the apparatus to make it work with this new vehicle. I am including photos of both vehicles to suggest different ways to make the experiment work. I have also done the experiment with a Dodge 4-door sedan (Intrepid). I suppose many different vehicles could be made to work. The main requirements are that the rear of the vehicle is vertical or nearly so for proper placement of the force-reading scales, and that the vehicle is not too large, so that reasonable amounts of force result in reasonable amounts of acceleration. If you (the teacher) do not own a suitable vehicle for this experiment try getting one of the parents involved with his or her own vehicle. They will have a great time with the students.

Achieving results within 5% of the predictions was only possible because while doing this experiment over and over I chased lurking variables like a bloodhound for over a dozen years. I learned a great many details that can make this experiment a resounding success. Naturally, I am going to present all these here in this chapter, but the downside of doing so is that the chapter will be somewhat long. Believe me, this experiment is so much fun that it is all worth it.

1 Unfortunately, I have been unable to locate this article in order to cite it appropriately.

Even though the lengthy instructions may make this experiment appear daunting, in its basic form it is actually easy to do and requires no special equipment. Students simply push a car using inexpensive bathrooms scales to measure and monitor the force, while other students time the vehicle in order to establish an experimental value for the acceleration. The forces the pushers apply are used to work up theoretical values for the acceleration. I suggest that when you perform this experiment for the first time you go with this simple approach. Then whenever the budget permits, you can look into acquiring the equipment and building the apparatus for the more sophisticated approach.

Setup and data collection for this experiment can be completed in approximately 50 minutes.

Materials Required (for the class)

Note: If bathroom scales are used for the experiment, you will need two of them. If the PASCO equipment is used for the experiment and is fastened to a support rack as described below, then you will still need one bathroom scale for weighing the driver and the support rack.

1. bathroom scales (2); (Stay away from digital scales. Humans cannot respond as fast to changing numerals as they can to a swinging pointer. Use inexpensive, old-fashioned scales that read with a dial or needle.)
2. pick-up truck, KIA Soul, or other vehicle for the purpose
3. measuring tape, such as the 30 meter, wind-up metric tape AP6323 available from Flinn Scientific (flinnsci.com)
4. stop watch
5. duct tape

Additional optional equipment if digital readers are used:

6. PASPORT 2-Axis Force Platform, PS-2142 (2); (available from PASCO, pasco.com)
7. Xplorer GLX (2); (available from PASCO, pasco.com)
8. Force platform handle set, PS-2548 (2); (available from PASCO, pasco.com)
9. Force platform support rack (see the illustrations below for construction suggestions)

Experimental Purpose

Use Newton's Second Law of Motion to predict the acceleration of the vehicle under different applied forces and compare the predicted accelerations to experimental values.

Overview

The entire class conducts this experiment as a group, sharing the data recorded. The idea is to push a vehicle with known, constant forces over a known distance (10.00 m) starting from rest while timing it with a stop watch. The resulting acceleration may be computed as

$$a = \frac{2d}{t^2}$$

Two students push the vehicle simultaneously, pressing on the rear of the vehicle with bathroom scales or other devices so they can monitor the forces they are applying. Four different values of force are applied, resulting in four different values of acceleration. Three trials are conducted for each force. A set of trials is judged valid if the three time measurements are within a one-second range from highest to lowest. For a given force value, the times from all three trials are averaged to determine the experimental value of acceleration.

The predicted values of acceleration for the four different applied forces are determined from Newton's Second Law,

$$a = \frac{F}{m}$$

Before the day of the experiment the teacher must drive the experimental vehicle to a weighing station to be weighed (full tank of gas, no driver). I use a local landscaping supply company that has a truck scale for weighing trucks hauling stone, and when I tell them I am a science teacher they are always happy to weigh my car. You can report the weight in pounds to the students and let them determine the vehicle mass for themselves. Values of acceleration are computed from the total applied forces and the vehicle mass. (The mass must include the mass of the experimental driver and the force measurement equipment, as described below.)

The acceleration predictions are much more accurate if friction forces are deducted from the values of force applied by the students. A good approximation for the total friction force is found by having one student push the car as slowly as possible while barely keeping it in motion at a constant speed. (This must be done in the location where the experiment is to be performed, because the slope of the pavement makes a huge difference in how much force is required to overcome the kinetic friction of the brake pads and wheel bearings.) The value of the force required to do this is deducted from each applied force to obtain the net force values used in Newton's Second Law for the predictions.

As recommended in the original article on this idea, I conducted this experiment for many years using two inexpensive bathroom scales purchased from a discount store for under $10 each. The students simply hold the scales against the back of the car or truck and watch the dial on the scale, adjusting the strength of their pushing to hold the force as steadily as possible on the desired value. The scales remain in place by friction while the forces are applied. The results are surprisingly good, especially considering that the forces are impossible for the pushers to hold steady. The forces bounce up and down above and below the desired value. But with two people pushing they average out well to give an average value close to the desired value.

Over the years as funds became available I looked into higher-tech ways of monitoring the forces. PASCO makes a nice tool for measuring the forces, the PASPORT 2-Axis Force Platform, that connects to a portable data collection tool called the Xplorer GLX. (Both of these are expensive, and you need two sets for this experiment. But the Xplorer GLX is a versatile tool that can be used for many other types of data collection, including several other experiments and demonstrations described in this book.) The force platforms are too bulky and heavy for the pushers to use them without support, so I built a wooden rack to mount on the back of the pick-up truck to hold the two force platforms. Now that I am doing the experiment with a KIA Soul, I modified the rack so it would work with this different vehicle. Both versions of the support rack are shown in the illustrations beginning on page 31.

The PASCO equipment allows one to collect data into a digital file and display the data graphically in a computer application for analysis. The display on the Xplorer GLX can also be set to show a simulation of an analog dial, which is much easier for the pushers to read and respond to than a digital display. One can also calibrate the maximum reading of the display of the Xplorer GLX for maximum resolution. I now conduct this experiment every year using the PASCO equipment. The students get a kick out of the digital equipment, and the whole set up is less finicky than doing the experiment with bathroom scales (which are hard to zero or tare, and tend to slip around). In summary, go high-tech if you can. But if you can't, this lab is still a ton of fun. The students love it and the data collection and analysis are very effective ways of learning about Newton's Second Law of Motion.

Experimental Conditions

The optimum conditions for doing this experiment would be inside a large, air-conditioned building, on a clean, smooth, level surface. If you have access to such ideal conditions take advantage of them. Here's why such conditions matter.

First, wind can make a significant difference in the acceleration of the vehicle. This problem is significantly worse when using a hatch-back vehicle with the hatch open, as with my KIA Soul. The open hatch catches the wind, affecting the net force on the car and causing large errors. So select a location for the experiment where the wind is blocked by a nearby building.

Second, in a parking lot all surfaces are intentionally designed to slope for proper drainage. This means that the best you can do is minimize the slope of the pavement, but you can't eliminate it. Select a location with as little slope as possible.

Third, the slope of the pavement may not be uniform, and different amounts of slope will produce different net forces on the car. Even over the 10-meter course of the car timing zone the slope can change enough to cause significant error. Select a location where the slope of the pavement is as uniform as possible.

The air conditioning is not really necessary. But in Texas, doing this experiment in September, the students pushing the car tend to get hot and sweaty (and stinky). Naturally, we gung-ho scientists never let little things like this get in our way, but I always wondered if I should try to persuade the Athletic Director to let us perform this experiment in the gym! If you have an outdoor basketball court on level concrete, that would be close to ideal. If the court is sheltered from wind then it would have everything you need except cool weather.

If you have to make do out in a parking lot somewhere, you must at least choose a location horizontal enough that the vehicle will not begin to roll by itself anywhere in the timing zone after given a little push.

Pre-Lab Discussion

Students should read the Student Instructions handout for basic information about the purpose of the experiment and procedures. Additionally, review the following items with students the day before the experiment:

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