5. Problem-Solving Labs

This chapter contains some materials that describe our cooperative-group problem solving labs. This material is described below.

Frequently Asked Questions About the Laboratory

Written for teaching assistants (TAs)

Introduction:

These lab instructions are probably different than those you are used to. You will not find a detailed discussion of the principles explored by the lab; you will not find any algebra deriving the equation to be used in the lab; and you will not find step-by-step instructions telling the students what to do. These labs allow students to practice making decisions based on the physics presented in the other parts of the class: the discussion sections, the lecture, and the text.

The lab instructions are divided into 4 to 5 two-to-three-week units (labs), an equipment appendix, and five technique appendices. The labs themselves are comprised of an introduction page and several problems. Notice that we do not do experiments in our laboratory. The lab problems are similar to the ones found at the end of a textbook chapter or on a quiz, which the students to solve and then compare the solution to nature. Typically an problem should take the students about an hour to complete (if they have done their homework). They should analyze all the data and reach a conclusion in class before starting a new problem. The problems are further broken down into sections which represent the process expert researchers use in a laboratory. The sections are: introduction to the problem, description of the equipment, a prediction of the outcome, method questions, exploration, measurement, analysis and conclusion.

Each problem begins by describing a context in which a problem arises. This context has been selected to be relevant to the students. The equipment is then described in enough detail to allow the students to predict the outcome of the problem. The questions in the next two sections (Prediction and Method Questions) are to be answered by the students **before** they come into lab and will be checked by the lab instructor (you) *within the first five to ten minutes of class*. The Prediction is a quantitative or qualitative solution to the problem. The Methods Questions are designed to help the student either complete the prediction or plan the analysis the data before they come to lab. Typically, the introduction to each lab class will begin when you ask the members of each group to arrive at a consensus about one or more of these questions and then put its answer on the blackboard. Then have a class discussion comparing and contrasting these answers. Remember, the purpose of the introduction is to get students to make an intellectual commitment to the lab. They do not need to arrive at the correct answer to the questions until after they have completed the problem. The Exploration section encourages the students to get familiar with the apparatus so they will understand the range over which valid measurements can be made. The Measurement section asks the students to think about the kinds of measurements needed to test the prediction. The Analysis section asks the students to process their data so that they can interpret their results in the Conclusions section.

***Grading*:**

Students are graded on a ten point scale. They receive one point per week for their prediction and the answers to the methods questions, and they receive another point each week for keeping a competent lab journal. Each student is also required to write a lab report for one problem, which is different for each member of a group. That problem is assigned by the instructor (you) at the end of the two week lab period. This report should be a concise and self-contained technical report which is essentially a clarification of the student's lab journal. It should only be about three pages in length. You will assign up to six points for this report.

To encourage cooperation in lab groups, the students should be awarded bonus points if everyone in their group receives more than eight points on the report. You may want to generate a little peer pressure for preparation by giving a bonus point if everyone in a group comes to lab with a complete set of answers for the prediction and methods questions.

Frequently Asked Questions:

What goals are addressed by these labs?

There are many possible reasons of doing a physics laboratory. For example, a lab could allow students to:

- confront their preconceptions of how the world works;
- practice their problem solving skills;
- learn how to use equipment;
- learn how to design an experiment;
- observe an event which does not have an easy explanation to realize new knowledge is needed;
- gain an appreciation of the difficulty and joy of doing and interpreting an experiment;
- experience what real scientists do; and
- have fun by doing something more active than sitting and listening.

It is impossible to satisfy all of these goals with a single laboratory design. Because this course follows the traditional structure of learning physics through solving problems, we have focused the laboratories toward **PROBLEM SOLVING**. Since the most important reason that our students cannot solve physics problems is that they have misconceptions about the physics, our second goal is to confront some of those misconceptions in the laboratory.

Why this style of lab?

Most physicists feel that labs are an essential part of a physics course because physics describes reality. Some have gone so far as to state that all physics instruction should take place in the laboratory. Nevertheless, labs are the most expensive way to teach physics. Research to determine the benefit of labs in teaching physics has consistently shown that labs which give students explicit instructions in a "cookbook" style have little value, particularly to address a problem-solving goal. The research also shows that "hands-on" experience is an efficient way of overcoming misconceptions. In our teaching environment, the laboratory is the only opportunity for you to interact with small groups of students during an extended period. Because the students have specific and visible goals, it is easier for the instructor (you) to determine their physics difficulties by observing them. Solving a problem in the laboratory requires the student to make a chain of decisions based on their physics knowledge. Wrong decisions based on wrong physics lead to experimental problems that you can observe and correct.

How can I make my students like and value the labs?

Instructor attitude is the most important factor in determining what the students like. If the instructor likes the labs and thinks they are valuable, then the students will tend to like the labs. The converse is also true. Even before starting the class, many students consider labs as "busy work" which have nothing to do with the content of the course. Labs have required attendance, so some students see their object as getting a task done as fast as possible so they can leave -- the "take-the-data-and-run" approach. This view is reinforced when (a) students are given step-by-step instructions focused on doing the task as efficiently as possible; (b) the lab instructor spends a majority of the lab time helping groups get their apparatus working so they can get done; (c) the lab instructions have all the necessary information, so the students do not need to use the textbook or the lectures; (d) the problems are not seen as challenging; and (e) there is no reference to the labs in the lectures or on tests.

The physical appearance of the lab is also very important in determining student attitude. Students will also dislike the labs if they are overly frustrated in their attempts to operate in the laboratory environment. An instructor who takes time to assure that the lab is neat and orderly before the students enter gives the message that the students' lab work is important.

Why have students work in groups?

The simplest answer is that a well functioning group is the most efficient way to solve any problem. However, in this class we have more definite educational reasons. Students working in groups must discuss what their thoughts are -- they get practice in "talking physics." This discussion tends to bring their physics preconceptions (alternative conceptions) to the surface so they can deal with them. It is a cliché that the "best way to learn is to teach," but it is true. Working in the same groups in both laboratory and discussion section allows students to become more familiar with each other so that they feel comfortable enough to discuss their physics difficulties. Having the same groups and instructor for both the laboratory and discussion section also explicitly connects the lab to the rest of the course. In addition, students working in groups make teaching more manageable for the instructor. Instead of trying to serve 18 individual students, you interact with 6 groups, so you can be their "coach" to help them become better problem solvers. By pooling their knowledge and experiences, members of a group will get "stuck" less often which leaves the instructor freer to concentrate on groups which are on the wrong track.

Why are there so many problems in each lab?

These labs have been written so that there are more problems than the typical group can complete in the time allotted. This emphasizes that the function of the lab is to learn the physics not to get the problems "done." The teaching team for each course can then choose a preferred order of problems and the minimum number of problems to be completed to match the emphasis of the lectures. In addition, the extra problems allow each lab instructor (you) the flexibility to select the material to meet the needs of each particular group. Some of your groups may understand the material and need to be challenged with more difficult problems to deepen their knowledge. This also keeps these groups from becoming bored. On the other hand, some groups will have difficulty in understanding the basic physics being presented and may need to concentrate on a single, straight-forward problem or do a second very similar problem.

Why don't the lab instructions give the necessary theory?

This is to emphasize that the laboratory is an integral part of the entire course. The theory is available in the textbook and the preparation section for each laboratory gives which sections are to be read. Reading the text and doing the predictions and method questions for each problem gives an adequate preparation for the lab. A computer check out is used to assure that each student has a basic understanding of the necessary text material before coming to class. Doing the lab problems should help, with the guidance of the lab instructor, clarify and solidify the ideas in the text and in the lecture.

What is the reason for giving minimal laboratory instructions?

One of the primary goals of the laboratory is to help students learn to solve physics problems *better*. Good problem solving requires informed decision making. Most of these students need a great deal of practice in making analytical decisions. The labs are designed to leave most of the decisions up to the students. As with any problem, usually there are several correct paths. Discussing the possible choices within the group gives each student the opportunity to solidify correct concepts and dispel alternative conceptions. This freedom also allows groups to make incorrect choices. It is another true cliché "that we learn from our mistakes". Observing these incorrect decisions allows the instructor (you) to teach to the needs of the particular students or groups.

Why should the students write up lab problems?

No matter how conscientious the lab instructor is, many students will leave the lab with some of the same misconceptions as when they entered. The presentation of the course material may also generate new misconceptions. Reading a student's words gives the instructor valuable knowledge about that student's knowledge of the physics. This can help you direct your teaching more effectively. In addition, these students need to begin the process of clear, concise, meaningful written technical communication that they will need in their careers.

What is the function of the pre-lab computer check out?

This set of questions are available in selected computer labs around campus. They are designed to make sure that students have read the relevant sections of the text before they come to your laboratory. The questions require minimal understanding of the concepts in the text and are a good preparation for the lectures as well as the laboratory. Students are required to score at least 75% to pass. If a student misses a question, the test is expanded to give them another chance to answer a similar question correctly. The more questions that the student misses, the longer the test. Student can take the check out as many times as they wish. They can use their textbook, their notes, and consult with other students when they take the check out. The important thing is that they come to lab prepared. When a student keeps getting the same question wrong even though they are sure they put in the right answer, it is almost never a computer glitch -- usually the student has an alternative conception. This is an excellent opportunity for instruction. Each students' scores, questions missed, the number of times the check out is taken, and the time the student takes are all recorded in a file for your use. A student who has read the material with some understanding should pass the check out in less than 15 minutes. Of course, this rarely happens. Typically students read their text *for the first time* while they are taking the test, so they can take from 30 - 45 minutes to learn the information. If a student is taking more than 60 minutes to pass the test, this is probably too much time and you should discuss the problem with the student.

Typical Objections To Cooperative Group Discussion Sections

TRADITIONAL VERIFICATION LABS	U OF MN PROBLEM-SOLVING LABS	INDUCTIVE OR "INQUIRY LABS
MAJOR GOAL: To illustrate, support what is being learned in the course and teach experimental techniques.	**MAJOR GOAL:** To illustrate, support what is being learned in the course.	**MAJOR GOAL:** To learn the process of doing science.
INTRODUCTION: • Students are given quantity to compare with measurement. • Students are given theory and how to apply it to the lab. • Students are given the prediction (value measurement should yield).	**INTRODUCTION:** • Students are given a context-rich problem to solve. • Students must apply theory from text/lecture. • Students predict what their measurements should yield.	**INTRODUCTION:** • Students are given a question to answer. • Sometimes students are given related theory. • Sometimes students are asked for a prediction.
METHODS: • Students are told *what* to measure. • Students are told *how* to make the measurements.	**METHODS:** • Students are told *what* to measure. • Students decide in groups *how* to make the measurements (guided qualitative exploration).	**METHODS:** • Students decide *what* to measure. • Students decide *how* to make the measurements (open-ended qualitative exploration).
ANALYSIS: • Students usually given analysis technique(s). • Emphasis is on precision and experimental errors.	**ANALYSIS:** • Students decide in groups details of analysis. • Emphasis is on concepts (quantitatively).	**ANALYSIS:** • Students must determine analysis techniques. • Emphasis is on concepts (qualitatively).
CONCLUSION: Students determine how well their measurement matches the accepted value.	**CONCLUSION:** Students determine if their own ideas (prediction) match their measurement.	**CONCLUSION:** Students construct an hypothesis to explain their results.

Outline: General Plan for Teaching a Laboratory

	What the Students Do	What the TA Does
Opening Moves: 15 min	• Do their individual predictions before they get to class. • Arrive at group consensus about their prediction(s). • Recorder/checker puts *group* prediction on board. • Participate in discussion about prediction(s).	0. Get to the laboratory classroom early. 1. Check individual predictions in grade book. 2. Diagnose major conceptual problems. 3. Lead class discussion about *reasons* for group predictions 4. Assign groups problems to complete. 5. Tell class time they need to stop and remind managers to keep track of time.
Middle Game	• Do the assigned laboratory problems: - explore apparatus - decide on measurement plan - execute measurement plan - analyze data as they go along - discuss conclusions . . .	6. Diagnose problems 7. Intervene when necessary 8. When appropriate, grade journals 9. Ten minutes before you want them to stop, tell students to find a good stopping place and clean up their area. Make sure you are done grading journals. Also pass out group functioning forms at this time.
End Game: 10-20 min	• Finish problem, clean up lab area. • Participate in class discussion.	10. Select one person from each group to put their results or data on the board. 11. Lead a class discussion of these results. 12. If necessary, lead a class discussion of group functioning 13. Tell students what problem to do predictions for next week. 14. Assign students problems to write up (if last lab).

Detailed Advice for TAs about General Laboratory Lesson Plan

0. Get to the laboratory classroom early.

When you get to the classroom, go in and lock the door, leaving your early students outside. The best time for informal talks with students is after the lab!

Prepare the classroom by checking to see that there is no garbage around the room and that the proper equipment is on student tables and on the front table. On the blackboards, provide space for each group to present its predictions. If you have changed groups, list the new groups on the board at this time also. Let your students in when you are prepared to teach the lab.

To keep the students from starting the problem before they discuss their predictions, set aside a small but necessary piece of equipment. Pass this out only after the predictions and discussion are complete.

1. Check students' individual predictions in your grade book

This should be done within the *first five to ten minutes* of the starting time for the laboratory session, **and not after**. That is one of the best ways that has been found to encourage students to be on time to class.

2. Diagnose major conceptual problems

This is easier to do for some problems than others. When possible, the mentor TAs will pass out research papers on common alternative conceptions that relate to current laboratories, and alternative conceptions will be discussed in the weekly all-TA meetings.

No matter how severe students' conceptual problems seem to be, how unprepared students seem to be, **DO NOT LECTURE** to students at the start of lab. They have an opportunity to see the theory of physics in their lectures and textbooks, but lab gives them an opportunity to find out for themselves whether they are right about the way the world works. Even if the lecturer has not yet covered the material (which happens occasionally), **DO NOT LECTURE** the students about the concepts or lab procedures. Many lab problems serve as good introductions to a topic, and need only minimal reading from the text for students to be able to complete the Predictions and Methods Questions before the lab.

3. Lead class discussion about reasons for group predictions

This is important! Many students can come up with correct answers or reasonable looking graphs for strange reasons that do not follow the accepted laws of physics. If you do not discuss these reasons, your students will never realize later that their reasoning is incorrect. DO NOT TELL THE STUDENTS IF THEIR PREDICTIONS ARE CORRECT! This would spoil the whole purpose of the labs.

4. Assign groups problems to complete (if necessary)

If you have a group that is working very quickly, assign them longer or harder problems. If you have a group that is experiencing great difficulties, remember that it is better that they spend two or even three hours on the first problem, and learn it, than that they work quickly and do not learn.

5. Tell class when (at what time) they need to stop and remind managers to keep track of time.

If you see that there are prevalent or varied alternative conceptions shown in students' group predictions and reasons, you will want to stop students earlier so that you can have a longer discussion of their results. If, on the other hand, students seem to understand the relevant physics before they begin their laboratory problem, you will not need as much time for discussion. The students should then be able to complete the problem very quickly to check their prediction.

6. Diagnose any initial problems getting started

Once the groups have settled into their task, spend about five minutes circulating and *observing* all groups. Try not to explain anything (except trivial clarification) until you have observed all groups at least once. This will allow you to determine if a whole-class intervention is necessary to clarify the task (e.g., Be sure to . . .).

7. Monitor groups and intervene when necessary

When students work in cooperative groups, they make hidden thinking processes overt, so these processes are subject to observation and commentary. You will be able to observe how students are constructing their understanding of physics concepts and the problem-solving strategy.

While groups are working, a significant fraction of your time should be spent monitoring (observing and listening to group members) in order to see

- what they do and do not understand, and
- what problems they have working together cooperatively.

With this knowledge, your interventions can be more efficient. **DO NOT** get trapped into going from group to group explaining the task/physics or answering questions. If you begin intervening too soon, it is not fair to the last groups. By the time you recognize that all groups may have the same difficulty, the last groups will have wasted considerable time.

a Monitoring

- Establish a circulation pattern around the room. Stop and observe each group to see how easily they are solving the experimental problem and how well they are working together. Don't spend a long time with any one group. Keep well back from students' line of sight so they don't focus on you.
- Make notes about student difficulties with the task and with group functioning so you know what end-game moves to make.
- If several groups are having the **same** difficulty, you may want to stop the whole class and clarify the task or make additional comments that will help the students get back on track (e.g., I noticed that you are all . . . Remember to . . .) Another strategy is to stop the class and have one group (or several groups) **show** the class how they decided to make a certain measurement or carry out a particular analysis. You can then spend a few minutes discussing how that measurement or analysis could be done most effectively.

b. Intervening

- From your observations (circulation pattern), decide which group (if any) is obviously struggling and needs attention most urgently. Return to that group, watch for a moment and then join the group at eye level. One way to intervene is to point out the problem and ask the appropriate group what can be done about it. This establishes your role as one of **coach** rather than answer-giver. Another way to intervene is to ask them (a) What are you doing? (b) Why are you doing it? and (c) How will that help you? Try to give just enough help to get the group on track, then leave.
- One way to coach is to first diagnose the type of problem (e.g., managerial, came to decision too quickly without considering all the options, can't agree on what procedure to use, etc.) Then ask: "Who is the manager (or skeptic, or checker)? What should you be doing to help resolve this problem?" If the student doesn't have any suggestions, then you could model several possibilities.
- If you observe a group in which one student does not seem to be involved in the discussion and decisions, ask that student to explain what the group is doing and why. This emphasizes the fact that all group members need to be able to explain each step in solving the experimental problem.
- If a group asks you a question, try to turn the question back to the group to solve. Again, try to give just enough help to get the group started, then leave.

8. When appropriate, grade journals

This should be easy and quick to do. Check to see that students are keeping track of their data and that they are doing analysis in their lab journals *as they go along*. If they are not, tell the students they have lost their journal point(s). Losing a point once will prompt almost any student to improve his or her journal keeping.

9. Ten minutes before you want them to stop, tell students to find a good stopping place and clean up their area.

Make sure you are done grading journals. Also pass out group functioning forms at this time (if necessary, about every 2 - 3 weeks). (Note: Another common teaching error is to provide too little time for students to process the quality of their cooperation. Students do not learn from experiences that they do not reflect on. If the groups are to function better next time, members must receive feedback, reflect on how their actions may be more effective, and plan how to be even more skillful during the next lab or discussion session.)

When you were an undergraduate, your laboratory instructor probably did not stop you to have a class discussion at the end of the laboratory period. Doing this is one of the hardest things you will have to do as a TA. You may be tempted to let students keep working so that they can get as much done as possible, or to let them go home early so that they like you better. However, research has shown that students do not learn from their laboratory experiences unless they have the chance to process their information. One good way to do this is by comparing their results to their predictions with the whole class.

Most students do not want to stop, and may try to keep working. If it is necessary, to make your students stop working you can remove a small but essential piece of equipment (i.e., a battery or a connecting cable) so that they are forced to stop taking data. You are in charge of the class, and if you make it clear that you want the students to stop, they will.

10. Select one person from each group to put their results or data on the board, so all students can see what each group did.

Typically, the checker/recorder in each group is not selected. In the beginning of the course, select students who are obviously interested, enthusiastic, and articulate. Later in the course, it is sometimes effective to occasionally select a student who has not participated in the labs as much as you would like. This reinforces the fact that *all* group members need to know and be able to explain what their group did.

11. Lead a class discussion of these results.

A whole-class discussion is commonly used to help students consolidate their ideas and make sense out of what has been going on in the lab. Discussions serve several purposes:

- to summarize what students have learned;
- to help students find out what other students learned from the same problem;
- to produce discrepancies which stimulate further discussion, thinking, or investigations; and
- to provide a transition to the next problem.

These discussions should always be based on the groups, with individuals only acting as representatives of a group. This avoids putting one student "on the spot." The trick is to conduct a discussion about the results without (a) **telling** the students the "right" answer or becoming the final "authority" for the right answers, and (b) without focusing on the "wrong" results of one group and making them feel stupid or resentful. To avoid these pitfalls, you could try starting with general, open-ended questions such as:

- How are these results the same?
- How are these results different?

Then you can become more specific:

- What could be some reasons for them to be different?
- Are the differences important?
- Do these differences indicate a real difference in the physics, or are they a matter of judgment (e.g., decisions about starting times and positions for a graph).

Always encourage an individual to get help from other group members if he or she is "stuck."

Encourage groups to talk to each other by redirecting the discussion back to the groups. For example, if a group reports a certain result or conclusion, ask the rest of the class to comment: "What do the rest of you think about that?" This helps avoid the problem of you becoming the final "authority" for the right answer.

Students should be able to explain to their classmates how they collected and analyzed their data in order to come up with the answer to the experimental problem. If their predictions were very different, ask students to think about and discuss why they might have thought differently before and after the lab.

12. If necessary, lead a class discussion about the group functioning.

Discussing group functioning occasionally is essential. Students need to hear difficulties other groups are having, discuss different ways to solve these difficulties, and receive feedback from you.

- Randomly call on one member from each group to report either
  - one way they interacted well together, or
  - one difficulty they encountered working together, or
  - one way they could interact better next time.
- Add your own feedback from observing your groups (e.g., "I noticed that many groups are coming to an agreement too quickly, without considering all the possibilities. What might you do in your groups to avoid this?")

13. Tell students what problem to do predictions for next week

You will decide what problems all students should do in your team meetings. If there is extra time, you can decide what problem all students will do based on your knowledge of the conceptual difficulties your students have experienced up to this point.

14. Assign students problems to write up (if last session of lab).

Each student will write up one problem from each lab individually. If there was one person in a group that was not participating as well as you would like in a particular problem, you might want to assign that problem to the student. This way either the group will help the student catch up with the important information, or the student will be taught (by the bad grade you will give) to participate in the future.

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2nd Semester Laboratory, Calculus-Based Introductory Physics

Notes:

WELCOME TO THE PHYSICS LABORATORY!

Physics is our human attempt to explain the workings of the world. The success of that attempt is evident in the technology of our society. We are surrounded by the products resulting from the application of that understanding, technological inventions including clocks, cars, and computers. You have already developed your own physical theories to understand the world around you. Some of these ideas are consistent with the accepted theories of physics while others are not. This laboratory is designed to focus your attention on your interactions with the world so that you can recognize where your ideas agree with those accepted by physics and where they do not.

You are presented with contemporary physical theories in lecture and in your textbook. The laboratory is where you can apply those theories to problems in the real world by comparing your application of those theories with reality. The laboratory setting is a good one to clarify your ideas through discussions with your classmates. You will also get to clarify these ideas through writing in a report to be read by your instructor. Each laboratory consists of a set of problems that ask you to make decisions about the real world. As you work through the problems in this laboratory manual, remember that the goal is not to make a lot of measurements. The goal is for you to examine your ideas about the real world.

The three components of the course - lecture, discussion section, and laboratory - each serve a different purpose. The laboratory is where physics ideas, often expressed in mathematics, come to grips with the real world. Because different lab sections meet on different days of the week, sometimes you will deal with concepts in the lab before meeting them in lecture. In that case, the lab will serve as a good introduction to the lecture. In other cases, when the lecture about a topic precedes the lab, the lecture will be a good introduction to the lab.

The amount you learn in lab will depend on the time you spend in preparation before coming to lab.

Before coming to lab each week you must read the appropriate sections of your text, read the assigned problems to develop a fairly clear idea of what will be happening, and complete the prediction and method questions for the assigned problems.

Often, your lab group will be asked to present its predictions and data to other groups so that everyone can participate in understanding how specific measurements illustrate general concepts of physics. You should always be prepared to explain your ideas or actions to others in the class. To show your instructor that you have made the appropriate connections between your measurements and the basic physical concepts, you will be asked to write a laboratory report. Guidelines for preparing lab reports can be found in the lab manual appendices and in this introduction. An example of a good lab report is shown in Appendix F. Please do not hesitate to discuss any difficulties with your fellow students or the lab instructor.

Relax. Explore. Make mistakes. Ask lots of questions, and have fun.

WHAT TO DO TO BE SUCCESSFUL IN THIS LAB:

Safety always comes first in any laboratory.

If in doubt about any procedure, or if it seems unsafe to you, do not continue. Ask your lab instructor for help.

A. What to bring to each laboratory session:

1. Bring an 8" by 10" graph-ruled lab journal, such as University of Minnesota 2077-S to all lab sessions. Your journal is your "extended memory" and should contain everything you do in the lab and all of your thoughts as you are going along.

2. Bring a "scientific" calculator.

3. Bring this lab manual.

B. Prepare for each laboratory session:

Each laboratory consists of a series of related problems that can be solved using the same basic concepts and principles. Sometimes all lab groups will work on the same problem, other times groups will work on different problems and share results.

1. Before beginning a new lab, you should carefully read the Introduction, Objectives and Preparation sections. Read the sections of the text specified in the *Preparation* section. **Before you come to the lab, you must pass a short lab-prep test covering some basic material in the textbook.**

   These lab-prep tests are on computer and are designed to take about 15 minutes to complete. There are two designated computer sites where you may access the lab-prep tests: Physics 130, and Computer Science 3-166. Complete instructions are in *Appendix G*.

2. Each lab contains several different experimental problems. Before you come to a lab, be sure you have completed the assigned

Prediction and *Method Questions.* The Method Questions will help you build a prediction for the given problem. It is usually helpful to answer the Method Questions before making the prediction. **These individual predictions will be checked (graded) by your lab instructor *immediately* at the beginning of each lab session.**

This preparation is crucial if you are going to get anything out of your laboratory work. There are at least two other reasons for preparing:

a) There is nothing more dull or exasperating than plugging mindlessly into a procedure you do not understand.

b) The laboratory work is a **group** activity where every individual contributes to the thinking process and activities of the group. Other members of your group will not be happy if they must consistently carry the burden of someone who isn't doing his/her share.

C. Laboratory Problem Reports

At the end of every lab (about once every two weeks) you will be assigned to write up one of the experimental problems. Your report must present a clear and accurate account of what you and your group members did, the results you obtained, and what the results mean. A report is not to be copied or fabricated. To do so constitutes Scientific Fraud. To make sure no one gets in that habit, such behavior will be treated in the same manner as cheating on a test: **A failing grade for the course and possible expulsion from the University**. It should describe <u>your</u> predictions, <u>your</u> experiences, <u>your</u> observations, <u>your</u> measurements, and <u>your</u> conclusions. A description of the lab report format is discussed at the end of this introduction. **Each lab report is due, without fail, within two days of the end of that lab.**

D. Attendance

Attendance is required at all labs without exception. If something disastrous keeps you from your scheduled lab, contact your lab instructor immediately. The instructor will arrange for you to attend another lab section that same week. **There are no make-up labs in this course.**

E. Grades

Satisfactory completion of the lab is required as part of your course grade. *Those not completing* ***all*** *lab assignments by the end of the semester at a 60% level or better will receive a semester grade of F for the entire course*. The laboratory grade is 15% of your final course grade. Once again, we emphasize that **each lab report is due, without fail, within two days of the end of that lab.**

There are two parts of your grade for each laboratory: (a) your laboratory journal, and (b) your formal problem report. Your laboratory journal is graded by the lab instructor during the laboratory sessions. Your problem report will be graded and returned to you in your next lab session.

If you have made a good-faith attempt but your lab report is unacceptable, your instructor may allow you to rewrite parts or all of the report. A rewrite must be handed in again within two days of the return of the report to you by the instructor, in order to obtain an acceptable grade.

F. The laboratory class forms a local scientific community. There are certain basic rules for conducting business in this laboratory.

1. ***In all discussions and group work, full respect for all people is required.*** All disagreements about work must stand or fall on reasoned arguments about physics principles, the data, or acceptable procedures, never on the basis of power, loudness, or intimidation.

2. *It is OK to make a reasoned mistake. It is in fact, one of the more efficient ways to learn.*

This is an academic laboratory in which to learn things, to test your ideas and predictions by collecting data, and to determine which conclusions from the data are acceptable and reasonable to other people and which are not.

> What do we mean by a "reasoned mistake"? We mean that after careful consideration and a substantial amount of thinking has gone into your ideas you simply give your best prediction or explanation as you see it. Of course, there is always the possibility that your idea does not accord with the accepted ideas. Then someone says, "No, that's not the way I see it and here's why." Eventually persuasive evidence will be offered for one viewpoint or the other.
>
> "Speaking out" your explanations, in writing or vocally, is one of the best ways to learn.

3. *It is perfectly OK to share information and ideas with colleagues. Many kinds of help are OK. Since members of this class have highly diverse backgrounds, you are encouraged to help each other and learn from each other.*

   However, it is never OK to copy the work of others.

   Helping others is encouraged because it is one of the best ways for you to learn, but copying is completely inappropriate and unacceptable. Write out your own calculations and answer questions in your own words. It is OK to make a reasoned mistake; it is wrong to copy.

   > No credit will be given for copied work. It is also subject to University rules about plagiarism and cheating, and may result in dismissal from the course and the University. See the University course catalog for further information.

4. *Hundreds of other students use this laboratory each week. Another class probably follows directly after you are done. Respect for the environment and the equipment in the lab is an important part of making this experience a pleasant one.*

   The lab tables and floors should be clean of any paper or "garbage." Please clean up your area before you leave the lab.

   The equipment must be either returned to the lab instructor or left neatly at your station, depending on the circumstances.

In summary, the key to making any community work is **RESPECT**.

Respect yourself and your ideas by behaving in a professional manner at all times.

Respect your colleagues (fellow students) and their ideas.

Respect your lab instructor and his / her effort to provide you with an environment in which you can learn.

Respect the laboratory equipment so that others coming after you in the laboratory will have an appropriate environment in which to learn.

WHAT IS EXPECTED IN A PROBLEM REPORT? HOW IS IT HANDLED?

1. Before you leave the laboratory, have the instructor assign the problem you will write up and initial your cover sheet.

2. A cover sheet for each problem must be placed on top of each problem report handed in to the instructor. A cover sheet can be found at the end of every lab. *It gives you a general outline of what to include in a report.*

3. A problem report, is always due **within two days of the end of the lab**.

4. A problem report should be an organized, coherent display of your thoughts, work, and accomplishments. It should be written *neatly* (word processor recommended) in English that is ***clear, concise,* and *correct*.** It may help you to imagine that hundreds of people will read your report and judge you by it. **Communication is the goal of the report.** In many cases tables and graphs can aid communication.

5. A sample report is included in Appendix F. Listed below are the major headings which most lab reports use.

Major parts of a report:

COVER SHEET

See page 145 for a sample cover sheet.

STATEMENT OF THE PROBLEM

State the problem you were trying to solve, and how you went about it. Describe the general type of physical behavior explored, and indicate any theory from your textbook or lectures that was tested. If a relationship was tested, use diagrams and equations to explain your prediction.

DATA AND RESULTS

Following the problem statement is a Data and Results section, containing a detailed description of how you made your measurements and what results you obtained. This usually involves an organized and coherent display of labeled diagrams, tables of measurements, tables of calculated quantities, and graphs. Explanations of all results must occur in correct grammatical English that would allow a reader to repeat your procedure.

Mathematical calculations connecting fundamental physics relationships to the quantities measured should be given. Any interesting behavior should be explained. Difficulties performing the experiment should be described as well as any subtleties in the analysis.

All data presented must be clearly identified and labeled. Calculated results should be clearly identified. Anybody should be able to distinguish between quantities you measured, those you calculated, and those you included from other sources. Clearly assign uncertainties to all measured values -- without uncertainties, the data are nearly meaningless.

CONCLUSIONS

The Conclusions section should include your answers to the following questions: What generalized behavior did you observe? Was it different from what you expected? Why? (e.g., What were the possible sources of uncertainties? Did you have any major experimental difficulties?) How do your results compare with the theory presented in your textbook or during lectures? Can you think of any other ways to check your theory with your data?

SAMPLE COVER SHEET

PHYSICS ____ LABORATORY REPORT
LABORATORY I

Name and ID#: ____

Date performed: ________________ Day/Time section meets: _______________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor Initials: ____________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions completed in journal before each lab session)	
LAB PROCEDURES (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (GROUP PREDICTIONS) (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you -- no exceptions.

Notes:

LABORATORY III
FORCES

This laboratory will allow you to investigate the effect of specific interactions (forces) on the motion of objects. In the first problem, you will investigate the effect of forces on a sliding object. The second problem illustrates the application of the force concept and, in particular, the vector nature of forces, to a situation in which nothing is moving. The third and fourth problems investigate the behavior of a specific interaction (in this case, the frictional force.)

OBJECTIVES:

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

- Make and test quantitative predictions about the relationship of forces on objects and the motion of those objects for real systems.
- Use forces as vector quantities.
- Characterize the behavior of the friction force.
- Improve your problem solving skills.

PREPARATION:

Read Halliday, Resnick, and Walker: all of Chapter 5; Chapter 6, sections 1 and 2. Review the motion of a cart moving down a ramp.

Before coming to lab you should be able to:

- Define and use sine, cosine and tangent for a right triangle.
- Recognize the difference between mass and weight.
- Determine the net force on an object from its acceleration.
- Draw and use force diagrams.
- Resolve force vectors into components and determine the total force from the components.
- Explain what is meant by saying a system is in "equilibrium."
- Write down the force law for a frictional force.

Problem #2:
Forces in Equilibrium

These laboratory instructions may be unlike any instructions you have seen before. You will not find any worksheets, plug-and-chug formulas, or step-by-step instructions. Instead, the instructions are designed to get you thinking about physics. Since this design may be new to you, this first problem contains both the instructions to explore forces in equilibrium and an explanation of the various parts of the instructions. The explanation of the instructions are in this font and are preceded by double, vertical lines.

Why are we doing this lab problem? In these lab instructions, the first paragraphs describe a possible context and motivation for the problem you are about to solve. This emphasizes that physics is useful for solving real-world problems.

You have a summer job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned about the maximum amount of equipment each team member should carry to safely walk from tree to tree. If the walkway sags too much, the team member could be in danger, not to mention possible damage to the rain forest floor. You are assigned to set the load standards.

Each end of the rope supporting the walkway goes over a branch and then is attached to a large weight hanging down. You need to determine how the sag of the walkway is related to the mass of a team member plus equipment when they are at the center of the walkway between two trees. To check your calculation, you decide to model the situation using the equipment shown below.

?

How does the vertical displacement of an object suspended on a string halfway between two branches, depend on the mass of that object?

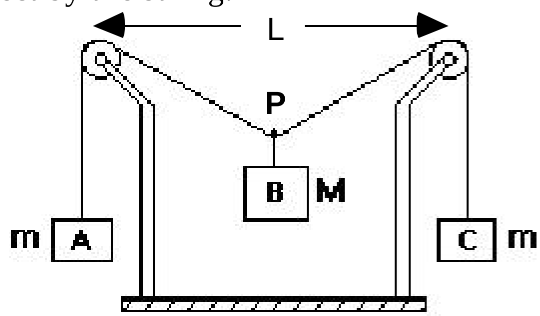
The question(s), framed in a box and preceded by a question mark, defines the experimental problem you are trying to solve. You should keep the question(s) in mind as you work through the problem.

EQUIPMENT

To make a prediction about what you expect to happen, you need to have a general understanding of the apparatus you will use before you begin. This section contains a **brief** description of the apparatus and the kind of measurements you can make to solve the experimental problem. The details should become clear to you as you use the equipment.

The system consists of a central object, B, suspended halfway between two pulleys by strings. The picture below is similar to the situation with which you will work. The objects A and C, which have the same mass (m), allow you to determine the force exerted on the central object by the string.

You do need to make some assumptions about what you can neglect. For this investigation, you will also need a meter stick and weights to vary the mass of B.



PREDICTION

All people, including scientists, have their own "personal theories" about the way the world works. One purpose of this lab is to help you clarify your conceptions of the physical world by testing the predictions of your personal theory against what really happens. For this reason, we will always predict an answer (what will happen)*before* collecting an analyzing the data. **Your prediction should be completed and written in your lab journal *before* you come to lab.**

Spend the first few minutes at the beginning of the lab session comparing your prediction with those of your partners. Discuss the reasons for any differences in opinion. It is not necessary that your predictions be correct, but it is necessary that you understand the basis of your prediction.

Calculate the change in the vertical displacement of the central object (B) as you increase its mass. You should obtain an equation which predicts how the vertical displacement of central object B depends on its mass, the mass of objects A and C, and the horizontal distance between the two pulleys.

Use your equation to graph of the vertical displacement of object B as a function of its mass.

Sometimes, as with this problem, you will be asked to use your knowledge of the concepts and principles of physics to predict the relationship between two variables in the experimental problem. For other problems, your prediction is an "educated guess" based on your knowledge the physical world.

METHOD QUESTIONS

Method Questions are a series of questions about procedures intended to help you solve the experimental problem. They either help you think about the experimental method for solving the problem (e.g., how to analyze data and/or display results), or they guide you through a problem-solving method for predicting the relationship between the variables in the problem. **Method Questions should be answered and written in your lab journal *before* you come to lab.**

To solve this problem it is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You should use a technique similar to that used in Problem 1 (where a more detailed set of Methods Questions are given) to solve this problem. You might also find the Competent Problem Solver useful.

1. Draw a sketch similar to the one in the Equipment section. Draw vectors which represent the forces on objects A, B, C, and point P. Use trigonometry to show how the vertical displacement of object B is related to the angle that the string between the two pulleys sags below the horizontal.

2. The "known" (measurable) quantities in this problem are L, m and M; the unknown quantity is the vertical displacement of object B.

3. Use Newton's laws to solve this problem. Write down the acceleration for each object. Draw separate force diagrams for objects A, B, C and for point P. (If you need help, see your text.) What assumptions are you making?

Which angles between your force vectors and your horizontal coordinate axis are the same as the angle between the strings and the horizontal?

4. For each force diagram, write Newton's second law along each coordinate axis.

5. Solve your equations to predict how the vertical displacement of object B depends on its mass (M), the mass (m) of objects A and C, and the horizontal distance between the two pulleys (L). Use this resulting equation to make a graph of how the vertical displacement changes as a function of the mass of object B.

EXPLORATION

Before you begin making measurements, it is useful to explore the range of variables over which your apparatus is reliable. Remember to always treat the apparatus with care and respect. Your fellow students in the next lab section will need to use the equipment after you are finished with it. If you are unsure about how the apparatus works, ask your lab instructor.

Most apparatus has a range in which its operation is simple and straightforward. This is its range of reliability. Outside of that range, complicated corrections need to be applied. You can quickly determine the range of reliability by making **qualitative** observations at what you consider to be the extreme ranges of your measurements. Record your observations in your lab journal. If you observe that the apparatus does not function properly for the range of variables you were considering measuring, you can modify your experimental plan before you have wasted time taking an invalid set of measurements. At this time you can also determine whether the behavior you observe agrees qualitatively with your predictions.

The result of the exploration should be a plan for doing the measurements you need. **Record your measurement plan in your journal.**

Start with just the string suspended between the pulleys (no central object), so that the string looks horizontal. Attach a central object and observe how the string sags. Decide on the origin from which you will measure the vertical position of the object.

Try changing the mass of objects A and C (keep them equal for the measurements but you will want to explore the case where they are not equal).

Do the pulleys behave in a frictionless way for the entire range of weights you will use? How can you determine if the assumption of frictionless pulleys is a good one?

Add mass to the central object to decide what increments of mass will give a good range of values for the measurement.

MEASUREMENT

Now that you have predicted how your measurement will go and have explored how your apparatus behaves, you are ready to make careful measurements. To avoid wasting time and effort, make the minimal measurements necessary to convince yourself and others that you have solved the experimental problem.

Measure the vertical position of the central object as you increase its mass. Make a table and record your measurements.

ANALYSIS

Data by itself is of very limited use. It is hard to tell much from a column of numbers or dots on a tape. Most interesting variables are those *derived* from the data, not direct measurements themselves. Your predictions may be qualitatively correct but quantitatively very wrong. To see this you must process your data.

Always complete your data processing (analysis) before you take your next set of data. If something is going wrong, you shouldn't waste time taking a lot of precise but useless data. After analyzing the first data, you may need to modify your measurement plan. If you do, be sure to **record the changes in your plan in your journal**.

Make a graph of the vertical displacement of the central object as a function of its mass based on your measurements. On the same graph, plot your predicted equation.

Where do the two curves match? Where do the two curves start to diverge from one another? What does this tell you about the system?

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

CONCLUSION

After you have analyzed your data, you are ready to answer the experimental problem. State your result in the most general terms supported by your analysis. **This should all be recorded in your journal in one place before moving on to the next problem assigned by your lab instructor.**

What will you report to your supervisor? How does the vertical displacement of an object suspended on a string between two pulleys depend on the mass of that object? Did your measurements of the vertical displacement of object B agree with your initial predictions? If not, why? State your result in the most general terms supported by your analysis.

What information would you need to apply your calculation to the walkway through the rain forest?

Estimate reasonable values for the information you need, and solve the problem for the walkway over the rain forest.

Occasionally in this lab manual, you will be asked to extend what you have learned in this problem to a slightly more sophisticated setting. While the Check Your Understanding questions are not required for your lab report, they are an excellent review of the problem and may appear on the quizzes for the course.

☑ **Check Your Understanding:** Estimate reasonable values for the information you need, and solve the problem for the walkway over the rain forest.

Instructor's Guide
Laboratory III: Forces

Teaching Tips

1. This is the first of the true *sets* of complete quantitative problem solving labs. (Problem #4 of Lab 2 is really the first complete problem solving lab.) Point out the difference to your students. Tell them of the new expectations of getting equations for their predictions as opposed to using an "educated guess" to determine the relevant physics quantity.

2. The prediction for Problem #2 is challenging for the students. This is one prediction where at least half the class will not have a complete prediction. Resist the urge just to solve the problem for the whole class. Work with the individual groups so that they get it. A whole class discussion can be useful to point out the important factors that go into the solution. The students need to be able to do this type of problem themselves.

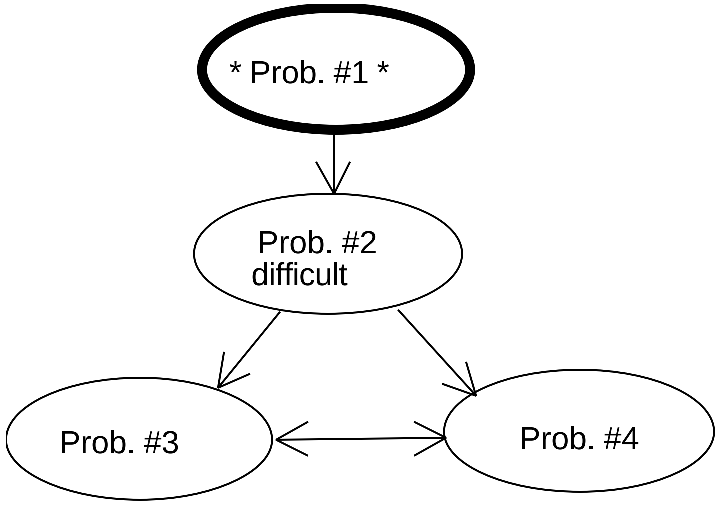
3. Problems #3 and #4 are similar. You might consider dividing the class in half and letting each half do one problem. The halves can then combine into two large groups, compare their data, and each large group can do a 5-minute presentation.

4. Students have plenty of alternative conceptions about forces. One force that is particularly confusing is the normal force. Be alert for students using the word "natural" to describe the normal force. This means that they do not associate the force with a direction. Explaining that in this case normal means perpendicular (make sure they know to what the force is perpendicular) may help.

5. The key to the friction problems is making measurements as consistently as possible. A good discussion topic is to ask what different factors would affect consistency.

6. Most of your students still have difficulty determining the components of vectors and understanding what these components mean. This lab repeats the use of vector components in the context of forces. Look for a recurrence of the mistakes you observed in kinematics.

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



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

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

Things to check out before teaching this lab:

- For Problem #1, it is nice, but not vital, that the cart avoid running over the string. Determine what you can suggest to students if they want to avoid the string.
- For Problem #2, make sure the pulleys that your students are using turn freely without binding. Replace any that don't.
- For Problem #2, determine how to best set up the apparatus so that you can help your students use the largest range of masses for M.
- For Problems #3 and #4, be sure that the end stops are not on the track. Having blocks running into the stops ruins the magnets and the Velcro pads.
- Also for Problems #3 and #4, the block slides differently if part of it is on the yellow ruler tape on the track. See how well you can avoid sliding the block along the yellow tape so that you are ready to give your students some advice if they need it.
- Try sliding the wooden block down the ramp at different angles (Problems #3 and #4) to determine where you will get consistent results. You don't need to take any data, careful qualitative observation should be enough.

Problem #1: Force and Motion

Purpose:

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

1. The students need enough string to hang over the pulley, but it should be long enough so that the mass hits the ground **before** the cart runs out of track.

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

3. Many students may have difficulty with the necessity of drawing the two force diagrams required to solve this problem. Most will want to equate the force on the cart with the weight hanging on the string. Avoid using the "clever" system of the weight + string + cart in your explanations. This system tends to confuse students and obscure the connection of forces with physical interactions.

4. This problem gives very good results if students remember to take into account the distortion from the camera lens.

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

Prediction:

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

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

Method Questions:

Problem #2: Forces in Equilibrium

Purpose:

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

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

2. Students will have trouble with the predictions. You should insist they do them before they arrive, but be prepared to dedicate class time to letting the students work on their predictions again after you compare group predictions in class. Lead a class discussion to highlight the difficulties that students are having and suggest solutions to those difficulties.

3. Resist the urge to do the problem for the class. The students can do this problem if you have confidence in them. Let them try.

4. Often students leave such quantities as θ in their equation. If another group does not point out that θ can be determined by measuring lengths, make sure you do so.

5. This is a good opportunity to encourage your students to use extreme cases to check their results. Ask them to determine what happens when $M \rightarrow 0, 8$. A discussion of taking limits is probably best done in the closing discussion after all measurements have been made.

6. The students need a large enough mass range to show them that the curve is **not linear**. If the students aren't using a large enough range of masses, remind them to look at how the deflection depends on other quantities. They can bring the pulleys together or add masses to the outside weights to increase the range of the central mass before it hits the floor.

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

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

9. An interesting test of the frictionless pulley assumption is to put unequal masses on each side (A and C) and find the maximum difference between A and C which causes the masses to move.

Major Alternative Conception of Students: Many students do not connect the concept of a force with a physical interaction. They can not determine the direction of a force from the physical connections of real objects. Some students still confuse the components of a force with the entire force.

Prediction:

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

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

Method Questions:

Problems #3: Frictional Force

Purpose:

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

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

1. Be sure the students get both the cart's motion and the falling object in the video.

2. Don't let the video run on too long.

3. It is important that cart accelerate smoothly along the ramp, otherwise the friction force will not be constant.

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

Prediction:

Method Questions:

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

Purpose:

- To show that the normal force does not have a fixed value. The normal force depends on the weight of the object (Problem #3) and on the angle of incline (Problem #4).

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

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

2. Don't let the block crash into the end stop. Be sure to remove the end stops before sliding the blocks down the track.

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

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

Prediction:

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

Method Questions:

EXPLORATORY PROBLEM
MAGNETS AND MOVING CHARGE

You are leading a technical team at a company that is redesigning the cathode ray tubes (CRTs) used for computer monitors. To introduce this project to a group of stock holders, you need to demonstrate how an electron beam can be moved across a screen by a magnetic field. You decide to use an ordinary bar magnet held outside of the CRT to deflect the electrons. Before you do the demonstration, you need to know the qualitative effect of bringing a bar magnet up to a CRT. In the laboratory you determine the how the direction and size of the electron deflection is related to the magnetic field direction, the magnetic field strength, and the velocity of the electron.

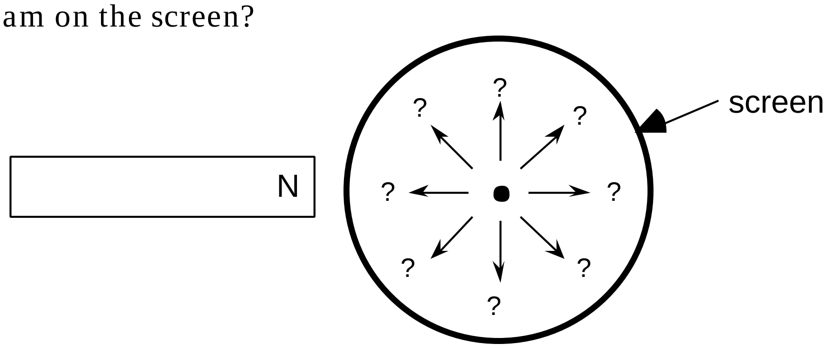
How will the electron beam in a CRT deflect in the presence of a magnetic field?

EQUIPMENT

For this problem you will need a cathode ray tube (CRT) and accessories, a bar magnet, a meter stick, and a compass. Review the information from Laboratory I and Appendix A regarding the design of the CRT and the proper way to use it.

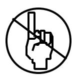
PREDICTION

If you bring a magnet near the side of the CRT, which arrow represents the deflection of the electron beam on the screen?



Does the size of the deflection increase or decrease as the magnet gets closer to the CRT? As you increase the size of the magnetic field? Does the size of the deflection depend on the speed of the electrons? Explain your reasoning.

EXPLORATION

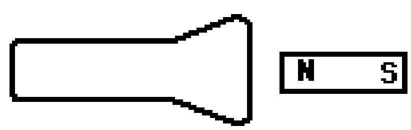


WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. Never grasp a wire by its metal ends.**

Connect the CRT according to the directions in Appendix A and your lab journal from Lab I. Select the accelerating voltage that gave the largest deflection for the smallest electric field based on your explorations from Lab I. Record the location of the undeflected beam spot.

Determine which pole on your bar magnet is the north magnetic pole. Make a qualitative field map of your magnet to make sure it is a simple dipole. If it is not, ask your instructor to replace it. Describe the magnetic field at the end of the magnet?

Place the magnet near the side of the CRT. Did the deflection match your prediction? Why or why not? Repeat this procedure for the south pole. Should there be any difference? In which direction did the beam spot deflect?



Put the bar magnet perpendicular to the screen of the CRT, do you see a deflection? Try this with both poles of the magnet. Record your results. Were they what you expected?

Can you orient the bar magnet so that it attracts or repels the electron beam?

Place the north pole of your magnet a fixed distance away from the side of the CRT near the screen. Record the deflection. Increase the speed of the electrons by increasing the accelerating voltage as much as possible. Calculate the increase in speed. How does deflection change? Try this with both poles of the magnet. Record your results. Were your results what you anticipated?

Place the north pole of your magnet a fixed distance away from the side of the CRT near the screen. Record the deflection. Increase the magnetic field adding more magnets. How does deflection change? Try this with both poles of the magnet. Record your results. Were your results what you anticipated?

What effect does the Earth's magnetic field have on the electron beam of a CRT? What is the direction of the Earth's magnetic field in your laboratory room? Arrange the CRT to see the maximum effect. The minimum effect. By measuring the electron deflection, what would you say is the relative strength of the magnet and the Earth's magnetic field in the lab. Remember to take account of the distance that the electron travels through each magnetic field. What is the effect of the Earth's magnetic field on the CRT beam relative to the Earth's gravitational field? How did this affect your results from Lab 1, Problem #5?

Devise your own exploration of the effect of a magnetic field on electrons using the CRT and the bar magnets. What variables can you control with the magnets and the CRT? Record your questions that will guide your exploration and check it with your lab instructor for safety before starting

ANALYSIS

Draw the picture relating the three vectors representing the velocity of the electron, the magnetic field, and the force on the electron that is consistent with your results.

CONCLUSION

Did the electron beam deflection in the presence of a magnetic field agree with your prediction? Why or why not? What was the most interesting thing you learned from this exploration?

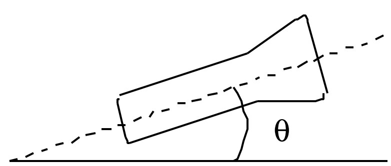
GRAVITATIONAL
FORCE ON THE ELECTRON

You are working in a research laboratory that is attempting to make a better electron microscope. The key to advancing the project is the precise control of a beam of electrons. For your study of electron control you decide to use a Cathode Ray Tube (CRT), the same device that is the basis of TV sets and most computer screens. In the CRT, electrons are emitted at one end of an evacuated glass tube and are detected by their interaction with a phosphorous screen on the other end. You know that every object in flight near the Earth's surface is subject to the gravitational force. From your physics experience you also know that the acceleration of all objects in free fall is the same, independent of their mass. Even though an electron has a small mass, it has the same gravitational acceleration as a baseball or a bullet. You worry that the gravitational force will deflect the electron from its path giving it the parabolic trajectory that you studied in the first semester of physics.

How does the Earth's gravitational force affect the motion of the electrons in the CRT?

EQUIPMENT

You will be using the Cathode Ray Tube (CRT) described in Appendix A. The fluorescent screen has a one-half centimeter grid in front of it so you can measure the position of the beam spot.



PREDICTION

Calculate how far an electron falls during its flight within the CRT when the CRT is *horizontal* ($\theta = 0^o$). Assume that the initial velocity is along the central axis of the CRT.

Will this electron deflection increase, decrease or stay the same as the angle is increased from horizontal ($\theta = 0^o$) to vertical ($\theta = 90^o$). Sketch the graph of the electron's distance from the center of the CRT at the screen (its deflection) versus angle of incline of the CRT from the horizontal. Explain your reasoning.

METHOD QUESTIONS

To test your prediction, it is useful to have an organized problem-solving strategy such as the one used below:

1. Draw a picture of the CRT in the horizontal position. Do not include the deflection plates shown in Appendix A since they will not be used in this problem. Be sure you have all the other components in your picture and you understand the function of these parts.

2. Draw the electron's trajectory from the time it leaves the electron gun until it hits the screen. Label all of the important kinematic quantities in the problem. Label all of the important forces on the electron. The target quantity for this problem is the electron beam deflection at the screen. The quantities you can measure in this problem are the position of the electron beam spot on the fluorescent screen, the initial electron accelerating voltage (V_{acc} in your picture), the distance from the end of the electron gun to the CRT screen, and the angle the CRT makes with the horizontal.

3. What physics principles will you use to solve this problem? To use kinematics, a motion diagram will probably be useful. Choose a convenient coordinate system and describe your reason for choosing it. How is the motion along one axis of your coordinate system influenced by the motion along the other axis? During what time interval will you analyze the motion of the electron? To determine the motion of the electron, you need to know its acceleration.

4. Dynamics (Newton’s second law) will allow you to determine the acceleration of the electron from the forces on it. What are the forces on the electron in that time interval? What is their direction? From the forces, determine the acceleration of the electron during that time interval along each of the coordinate axes you have chosen.

5. If the acceleration is constant along any axis of your coordinate system, you can use constant acceleration kinematics to describe the motion along that axis. If not, determine the behavior of the electron’s acceleration as a function of time and use calculus. Write down two equations (one for each coordinate axis) that describe the electron’s position at the screen in terms of its motion (positions, velocities, accelerations, and times).

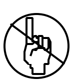
6. You can determine the electron’s velocity as it leaves the electron gun in the CRT from the force on the electron as it travels between the plates using conservation of energy. The magnitude of the electric field between two equally charged parallel plates is equal to the voltage between the two plates in Volts divided by the distance between the plates in meters. Assume that the direction of the electron leaving the electron gun region of the CRT is along the central axis of the tube. What is the direction of the electric field between the two plates? What is the direction of the electron just after it leaves the two plates? What assumption(s) have you made?

7. Examine your equations giving the electron's position at the screen. You can solve them if the number of unknowns in your equations is equal to the number of equations. Is it? If it is, solve your equations algebraically for the distance an electron will fall while traveling through a CRT. If it is not, write down additional equations that relate some of the unknown quantities in your equations to quantities that you know. Complete your solution by using the actual numbers that describe your situation.

8. Does your solution make sense? You can check by determining the time of flight of the electron. In that amount of time, how far would a ball drop in free fall? If the solution does not make sense, check your work for logic problems or algebra mistakes.

9. Now return to step 1 and solve the problem for a CRT pointed upward and an angle from the horizontal. What difference will this make to your solution?

EXPLORATION



WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. Never touch the conducting metal of any wire.**

Follow the directions in Appendix A for connecting the power supply to the CRT. Check to see that the connections from the power supply to the high voltage and the filament heater are correct, *before* you turn the power supply on. You should have between 250 and 500 volts of electric potential between the cathode and anode. After a moment, you should see a spot that you can adjust with the knob labeled "Focus". If your connections are correct and the spot still does not appear, inform your lab instructor.

Do you expect the gravitational deflection to vary as a function of the angle of the CRT with the horizontal? Try different orientations to see if you can observe any difference. Does the qualitative behavior of the electron deflection agree with your prediction?

For what orientation of the CRT is it impossible for the gravitational force to deflect the electron? This is the location of the beam spot when there is no gravitational effect on the motion of the electrons.

If you observe a deflection of the electron beam, determine if this deflection is or is not caused by the gravitational force. If it is not, what force do you think causes it and how can you minimize the effect of that force on your measurements? Is the deflection different if you move the CRT to a different position in the room?

Devise a measuring scheme to record the angle of the CRT and the position of the beam spot.

Write down your measurement plan.

MEASUREMENT

Measure the position of the beam spot at an orientation of the CRT for which you expect the gravitational deflection to be zero and the position at an angle for which the gravitational deflection should be maximum. Make measurements at several intermediate angles as well.

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix B) and with your estimated uncertainty (see Appendix C). Otherwise, the data are nearly meaningless.

ANALYSIS

Make a graph of the position of the electron beam spot as a function of the angle that the CRT makes with the horizontal.

If you observe a deflection, how can you tell if it is caused by the gravitational force? What else could cause a deflection?

Use your data to determine the size of the gravitational deflection of the electron.

CONCLUSION

Did your data agree with your predictions? Did you observe any deflection of the electron beam? Was it in the direction you expected? What could account for any aberrant behavior? How can you arrange your CRT to minimize that deflection?

Does the Earth's gravitational force affect the motion of the electrons in the CRT in a measurable way? State you results in the most general terms supported by your data. When you deflect the electron beam by an electric field what correction will you need to apply? How can you arrange your CRT to minimize that deflection?

Notes: