D. Discussion of Laboratory Explorations

The aims of the laboratory component of the course and suggested methods for incorporating it into the course are discussed in the introductory material of this *Instructor Guide*. There it was emphasized that hands-on activities are an essential component of the students' learning experience. Each of the activities presented in the *Student Guide* is only in suggestive, *preliminary* form. Instructors may utilize these materials directly, or adapt the materials to their own class needs and equipment. Many of the exercises deliberately involve "low-tech" equipment in order to enable adaptation to a variety of high- and low-tech environments.

This course offers a wide range of hands-on activities, each correlated with the contents of the textbook:

- Hands-on classroom demonstrations.
- Mini-Laboratory explorations.
- Outside student activities.
- Major laboratory explorations.

The pedagogical and content inspirations of each of these activities are indicated in the acknowledgments to the *Student Guide*, as well as below. The classroom demonstrations are suggested in the discussion of the appropriate chapter in this *Instructor Guide*. The chapter discussions also include references to the other suggested activities for each chapter. Some activities are listed in more than one chapter discussion, and instructors should introduce the activity where it seems most appropriate in the class schedule.

Each of the major laboratories consists of many subsections, which may be utilized individually as mini-laboratories or class demonstrations. In addition, two or more mini-laboratories might be utilized or expanded upon for use as a major laboratory. Finally, depending upon the class size, different sections of the major laboratories might be pursued by different groups, followed by class presentations by each group of the results and a general discussion of the overall conclusions.

The mini-laboratory "Reviewing Graphs" and the major laboratory "Investigating Measurements and Uncertainty" should be performed early in the semester. Students should also study the "Review of Units, Mathematics, and Notation," either on their own and in class or laboratory.

All of the suggested explorations should conclude by having the students evaluate their results in writing and/or orally. We suggest that considerable emphasis be placed on this summary evaluation, both as a writing exercise and as an exercise in summarizing the main features of a scientific experiment.

There are a number of computer programs and excellent Web sites that enable students to view and interact with simulations of the phenomenon discussed in the text. Lists of suggested resources are given in the references section elsewhere in this *Instructor Guide.*

COMMENTS ON SOME OF THE SUGGESTED MINI-LABORATORY EXPLORATIONS

1. Our Place in Space

These exercises help provide students with a direct grasp of the vast dimensions of the Solar System and the minute scale of the atom. Future teachers may be able to adapt this activity to the K-12 environment.

5. Relative Motion

The classic Project Physics video "Galilean Relativity: Ball Dropped from Mast of Ship," is an excellent supplement to this brief exploration. It is available in: *Physics: Cinema Classics* (College Park, MD: AAPT) and (Lexington, KY: Ztek Co.).

6. Galileo and Inertia

A portion of this mini-laboratory calls for the observation of a ball rolling down one inclined plane onto a second plane with an upward slope. Naturally this will require apparatus in which a smooth transition is possible from the first plane to the second. For the planes, we have used grooved wooden planks and ring stands to provide the incline. If a transition between planes is necessary, we have used a small piece of wood or a flexible plastic ruler held in place by hand. You may find that other arrangements of your own design work better.

9. How Do We Know That Atoms Really Exist? The Brownianscope

This scope is available inexpensively from Frey Scientific, Beckley Cardy Group, Mansfield, OH, 1-888-222-1332. A bare light bulb is also needed.

Students should be made aware or realize themselves that the observation of the random motion of smoke particles does not in itself prove the existence of atoms. Rather, it demonstrates the random motion that Einstein and others were able to relate to the random motions of atoms.

11. Spectroscopy

Inexpensive spectroscopes using plastic diffraction gratings are available from Cenco Central Scientific Company, Franklin Park, IL. The bare light bulb can be the same as the one used with the Brownianscope.

You should explain how a diffraction grating produces a visible spectrum through constructive interference. If a laser pen is available, students find informative a demonstration of constructive interference in the diffraction of a laser beam from the pits on a CD-ROM. The effect is not large but it is noticeable. Be careful to shine the laser and its reflection on a wall away from the class and from you. This also affords an opportunity to explain how binary data are displayed on a CD-ROM and subsequently read by a laser reader.

12. Radioactivity and Nuclear Half-Life

This investigation uses plastic simulated atoms in a kit provided by Frey Scientific, Mansfield, OH, 1-888-222-1332, part number S16402. An age determination using the decay of carbon-14 is simulated through instructions provided with the kit.

SUGGESTED MAJOR LABORATORY EXPLORATIONS

1. Investigating Measurements and Uncertainty

The study of measurement, uncertainty, and experimental error can be as thorough and as complicated as one wishes to make it. For this course, we have included only the most basic notions, in line with the needs of the course.

This exploration involves several measuring stations with the corresponding instruments. These might include: a sheet of paper and a metric ruler; a container of ice water and a thermometer, an "unknown" mass and a mass scale; a swinging pendulum; and a stopwatch to measure the period of swing.

2. Exploring Motion

This exploration is keyed directly to our text's Chapter 1, and should be performed in as close connection as possible with the text material. While the version here refers to the ticker-tape method of data gathering, instructors may easily adapt this exploration to more sophisticated data gathering and interfaces.

Sections 1.2 and 1.3 of the text refer to the example of a hockey puck on ice or a dry-ice disk on a table top. The motion is studied on a photograph produced using a stroboscopic disk moving over the camera lens. If this equipment is available, it should be used. But this laboratory assumes, as an alternative, the availability of a moving object, such as a cart, attached to a timing device, for example, one that places dots on a ticker tape or electrostatic dots on silvered paper. It also assumes the availability of a ramp or other means of "compensating" for friction. The preferred timer setting is 0.1 s.

Parts C and E may require the availability of English or metric tape measures. The English measurements should be converted to the metric system. Emphasize to the students that in science and in most of the world's everyday transactions, the metric system is used. Refer to the disaster of the Mars probe failure because some of the team used the English system, while the rest used the metric system.

Part F calls for a ball rolling down an inclined plane set at different angles of inclination. The equipment used in the mini-laboratory on "Galileo and Inertia" may also be used here. A grooved wooden plank, similar to the type of planks possibly used by Galileo (the matter is still debated) are available from Fisher Science, Science Education Division. (Aluminum tracks are available from Cenco Central Scientific Company, Franklin Park, IL). A timing device is also needed. A stop watch or other means may be used. Alternatively, students enjoy constructing a water clock from a large funnel emptying into a beaker. The amount of water in milliliters is then a measure of time.

Each part of the laboratory can also be used as a mini-laboratory. The entire laboratory can be done all at once or on two or more days.

There are many computer simulations of these motions, in addition to computer methods of data acquisition, analysis, and graphing. In using computer data acquisition and analysis be sure that students fully understand what is being recorded and how it is being analyzed.

Depending upon the class needs, your interests, and the availability of resources, some of the excellent interactive computer learning programs on motion might be introduced in order to reinforce and extend what students have already observed in the laboratory. They can return to the laboratory to compare with their computer results. One of the best learning programs designed for this subject is:

D. Trowbridge, *Graphs and Tracks*, Physics Academic Software (Woodbury, NY: AIP Press, 1994).

See also the motion "experiments" of the interactive Web cites listed in the reference section of this *Instructor Guide*.

3. Exploring the Heavens

As with the other explorations, individual parts of this exploration may be used as mini-laboratories, or each may be performed as an individual major exploration. In addition, the tasks outlined in each unit may be subdivided among various groups in the class.

Part A of this exploration assumes the availability of a heliocentric model of the Sun, Earth, and Moon. Such models are available, for example, from Nasco and Frey Scientific. Although the exploration does not call for it, students might also compare suggested positions of the Sun and Earth with the corresponding positions on a geocentric model of the Universe using a celestial sphere (available from the same companies). However, since the cost of these devices has risen so rapidly in recent years, it may not be possible to purchase enough devices so that students can work independently in small groups. If that is the case, the first part of the exploration could be performed as a demonstration activity involving the active participation of the entire class. In addition, the first part of the exploration might be supplemented, or even replaced, by an activity involving one of the excellent available computer planetarium programs. "Skyglobe: The Computer Planetarium," discussed below, is one such activity.

Parts B and D of this exploration are adapted from *Project Physics Handbook*, experiment 1-1, pp. 10–11. The instructions call for observations of the Sun during as much as 2 months, and observations of the Moon during a 1-month period. So this portion of the exploration should be started early in the semester.

Part E of this exploration is adapted from L.C. McDermott et al., *Physics by Inquiry*, vol. 2, p. 823.

Some of the suggested observations involve measuring the Sun's position. Students should be cautioned repeatedly *never to look directly at the Sun*. Explain why this is important.

Some excellent further suggestions on tracking celestial events may be found in the article by P.M. Sadler, D. Haller, and E. Garfield, Observational journals: An aid to sky watching, *J. College Sci. Teaching*, **29** (2000), 245–254.

4. Skyglobe: The Computer Planetarium

Skyglobe is a DOS-based shareware program created by Mark A. Haney of Ann Arbor, Michigan but released into the public domain. It is widely available on the Internet (it might also be available through the course Web site.) The suggested observations may be adapted to one of the many other similar programs now available.

5. Exploring Forces

This exploration is keyed to Section 3.4 of our textbook and should be performed in conjunction with the text.

Again the availability of a cart and a taped timing device or other means of data acquisition are assumed, as in the laboratory "Exploring Motion." It also requires that the friction force be balanced by the gravitational force, either by raising the cart on an incline or by attaching an accelerating weight, or by some other means. Additional apparatus needed includes: a spring-force meter or other means of exerting a measurable force, and a series of masses to add to the cart to yield the total masses indicated. In practice, it is often difficult to maintain a steady force using a spring-force meter over a large distance of acceleration. Depending upon the equipment available, a weight and pulley system might be used instead.

Part F calls for a volunteer on roller blades or on a bike or cart. A tape measure and stopwatches are also needed.

6. Exploring Force, Work, Energy, and Power

This laboratory is designed for the springs, hangers, and masses available from Frey Scientific, but the instructions may be adapted to other equipment. In setting up the spring, an initial mass of 500 g is attached to the spring (hanger + mass) in order to overcome the initial spring tension. This is defined as "zero mass," which may be confusing to some students. The laboratory calls for the study of only one spring, if there is sufficient time a second spring with a different spring constant can be examined.

See P. Froehle, Reminder about Hooke's law and metal springs, *Phys. Teach.*, **37** (1999), 368, on the initial tension of a spring.

7. Finding the Mechanical Equivalent of Heat

We suggest the use of a PVC pipe instead of a cardboard tube, because cardboard may tend to collect metal particles. Other metals might be used, if their specific heats differ noticeably from each other.

8. Exploring Heat Transfer and the Latent Heat of Fusion

This exploration is keyed to Chapters 7 and 16 of the textbook.

In this exploration, students also learn the value of careful laboratory procedures and the need for care in making measurements. They must also learn to coordinate their activities, for it is difficult for one person alone to perform all of the measurements involved.

Since Styrofoam coffee cups are often no longer available, we suggest the use of insulated thermos containers. This exploration requires the use of a lot of hot water. One or more coffee urns filled with water could be heated in advance of class, although they have the disadvantage that the water is not heated to boiling. The melting of the ice cube is almost immediate, and it does allow students to comprehend heat transfer in a very direct way.

Students will quickly discover that the hot water cools off very rapidly. They must take measures to keep the hot water covered in an insulated container as much as possible. Care must be taken to prevent scalding by the hot water.

9. Investigating Waves

In this exploration, students gain first-hand experience with one-dimensional waves on springs and two-dimensional waves on water. Typically, a ripple tank is used to study water waves, but the cost of a commercial ripple tank is now so high that many instructors may not want to purchase more than one such apparatus. (One can, however, be homemade.) At the other cost extreme, a large yellow cafeteria tray filled with water can also be used to demonstrate the behavior of water waves, although of course not as obviously as with a ripple tank. Yellow seems to be the best color for observing the waves. The light in the room must reflect off the surface at an appropriate angle for best observation of the waves.

10. Spacetime: A Computer Excursion into Relativity Theory

This exploration utilizes the computer program *Spacetime* by Professor Edwin F. Taylor, MIT. It is available from Physics Academic Software, American Institute of Physics, College Park, MD, which requires a license fee for laboratory use.

The suggested exploration utilizes only a small portion of the many features of this excellent program. We have found that this is more than enough for most nonscience students. But more features can be utilized, depending upon the abilities of the students.

11. Exploring Electric Charges, Magnetic Poles, and Gravitation

Observations of electrostatic phenomena are notoriously difficult on days on which the humidity is even slightly above normal. Nevertheless, students can observe electrostatic effects if they work quickly and recharge the apparatus often.

The material needed for each group is inexpensive and available from most vendors. It includes the following: acrylic and delvin rods; fur, silk, and cotton; a ring stand and crossbar; Scotch tape; cloth rag; a transparency; two bar magnets; a small compass; piece of string; and aluminum foil.

In addition, the instructor should provide for each group bits of material such as the following: small pieces of cork, paper, Styrofoam, grass seed, iron filings.

The iron filings should be spread on top of the transparency over the magnet, not directly on the magnet. At the same time as the students perform this observation, the instructor might also demonstrate it using an overhead projector with the iron filings sprinkled on the transparency as it lies on top of the magnet(s).

Most classes will probably require more than 2 hr to complete all of the observations suggested here. If time is limited, some of the observations on electrostatic charges may have to be excluded in order to include most of the observations on magnets.

12. Investigating Electric Currents I

Sections of this exploration may also be performed as mini-laboratories in class.

13. Investigating Electric Currents II

Most students are not familiar with electrical equipment, and some are fearful of it. The equipment used in both versions of this exploration is quite inexpensive and most may be obtained from Radio Shack or from one of the many vendors. The meters are easiest to find through a vendor. The connecting wires can be made on site. A "bread board" can be made from a piece of fiber board with drilled holes for screw-down posts. Students usually require guidance at first in familiarizing themselves with the equipment and how to use it.

For computer simulations, students may find one of the circuit simulations, such as "crocodile clips," of value.

14. Avogadro's Number and the Size and Mass of a Molecule

In this exploration, students gain a more direct sense of the size of a molecule and of the huge magnitude of Avogadro's number. They will also gain practice with scientific notation, and obtain a new sense of the meaning of multiplication and division, as recommended by A.B. Arons, *A Guide to Introductory Physics Teaching* (New York: Wiley, 1990), Chapter 1.

Since this exploration involves a considerable arithmetic manipulation of numbers in scientific notation, students should be fairly familiar with these procedures before beginning the exploration.