COLLEGE PHYSICS
LABORATORY GUIDE

PHYSICAL SCIENCE STUDY COMMITTEE
EDUCATION DEVELOPMENT CENTER

D. C. HEATH AND COMPANY
Lexington, Massachusetts

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The materials taken from the original and second editions of PSSC PHYSICS LABORATORY GUIDE and the Advanced Topics of PSSC PHYSICS included in this text will be available to all publishers for use in English after December 31, 1970, and in translations after December 31, 1975. Publishers desiring to use these materials are referred to the text PSSC PHYSICS.

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TO THE STUDENT

Although this Laboratory Guide is a much smaller volume than the textbook it accompanies, experimentation is the backbone of a sound introductory course in physics. It is in the laboratory that you can converse with nature, and it may surprise you to find out how far you can go by using your head, your hands, and a few simple tools!

In the age of automation you may expect "pushbutton" experiments. You will not find them in this Guide. Technical instructions are kept to the minimum necessary to get you started. From there on, some further guidance is given by leading questions, and then you are on your own.

Good working habits are useful. Always read the whole description of an experiment before you begin to work, so that you will have a clear understanding of what you are trying to do. Keep a complete record of your experiment as you perform it. Then you will have the data to refer to when needed, and sufficient information to understand what you did.

In the course of an experiment, whenever necessary, repeat your measurements a few times. Several readings usually are better than one. You should decide when more measurements are needed.

In many of these experiments you will require the help of one or more partners. Discuss results with your partners. You may learn more by working together on an analysis than by doing it alone.

You probably will not find it possible to do all the parts of every experiment. Do not rush; you will get more out of doing half the things suggested in an experiment thoroughly than all of them superficially. Often, part of the analysis can be done at home.

Most of the experiments in this Guide are taken from the Second Edition of PSSC PHYSICS and the Advanced Topics Supplement. Some were expanded or rewritten, and a few new ones were developed specifically for this Guide.

Since so many persons have contributed to the PSSC laboratory program over the years it would be difficult to list all individual contributions. But it goes without saying that this work was the result of a group effort.

Uri Haber-Schaim

December 1967

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EXPERIMENT 1
Short Time Intervals

Everybody knows how to measure the time it takes an athlete to run 100 yards. If reasonable accuracy is sufficient, an ordinary wrist watch with a second hand will do. But, can you measure the time it takes the vibrating clapper of an electric bell to make one complete vibration? Connect a battery to a bell for a few seconds and try! (Fig. 1.1.) You will find the time of one vibration so short that it is impossible to measure it with only a watch. In this experiment you will learn a method of measuring such short times.

Let us start with a larger "clapper," a loaded strip of steel, which does not vibrate so rapidly (Fig. 1.2). Pull the C clamp sidewise and release it. With your wrist watch, can you measure the time it takes the blade to complete one vibration?

Unlike the motion of the athlete, the motion of the blade repeats itself regularly. You can make use of this repetition by measuring the time it takes to complete, say, 10 vibrations. Will this increase the accuracy of your measurement?

You can easily count the vibrations of the blade and clamp, but you need a way of counting faster to be able to count the vibrations of the clapper. One way of doing this utilizes a disc stroboscope (Fig. 1.3). First cover all the stroboscope slits except one. While looking at the vibrating clamp, rotate the stroboscope slowly in front of your eye as shown in Fig. 1.3. By changing the rate of rotation, "stop" the clamp's motion at one end of its swing. How does the time of one rotation of the disc compare with the time of one vibration of the clamp? Is this the only possible relationship for which the blade appears to be stopped?

Your partner can now measure how long it takes for the stroboscope to complete ten revolutions. Then you can calculate how long it takes the clamp to make one vibration.

Move the C clamp to the middle of the blade (closer to the table) and try again to "stop" the motion of the vibrating blade

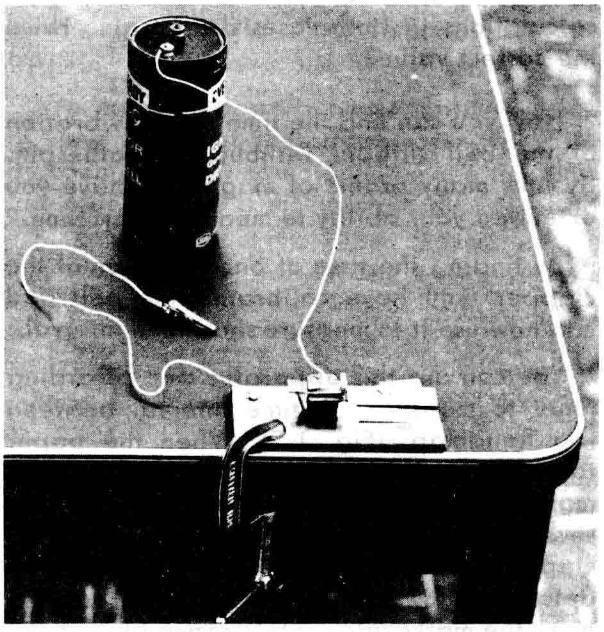

FIGURE 1.1

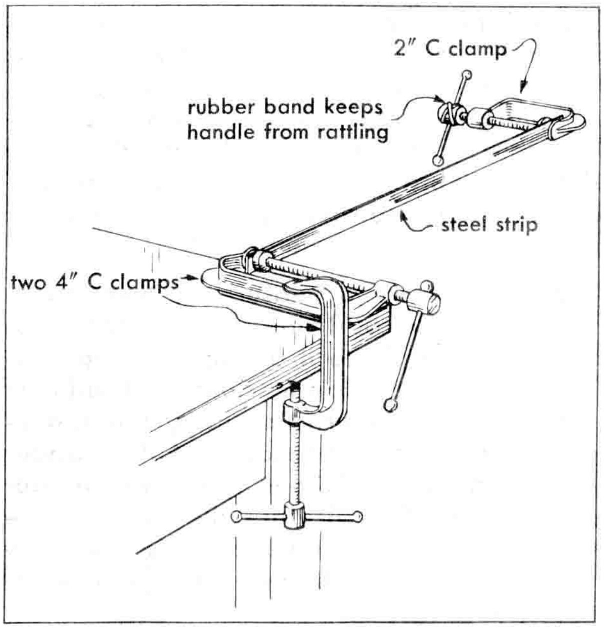

FIGURE 1.2

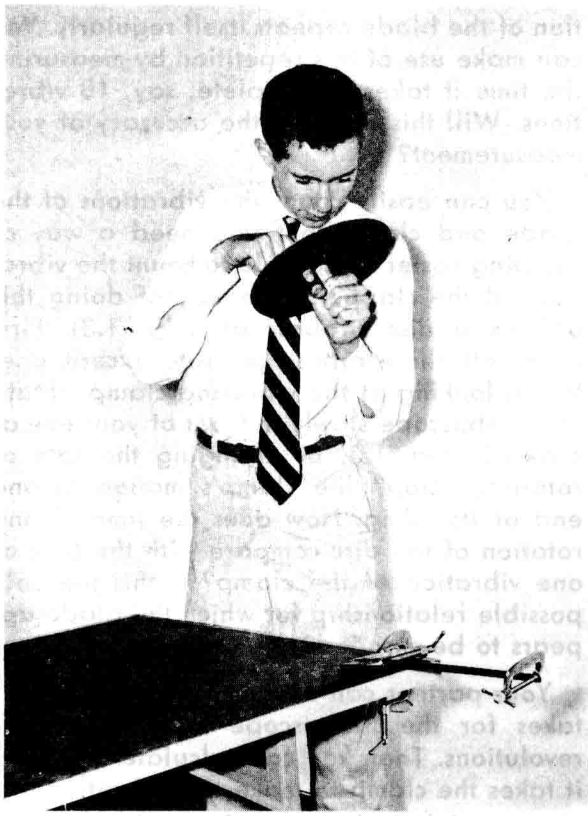

FIGURE 1.3

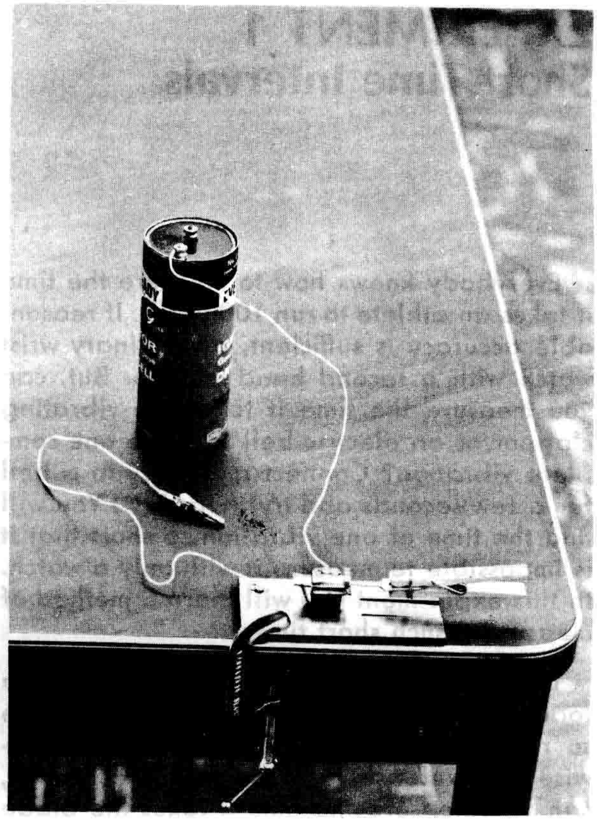

FIGURE 1.4

(pull the clamp and not the end of the blade). Try to "stop" the motion with two stroboscope slits open opposite to each other. What is now the relation between the time required to complete one revolution of the stroboscope and one vibration of the clamp? How long does one vibration take? What is the time of one complete vibration when the C clamp is moved still closer to the table?

Before you try to measure the time of one vibration of the bell clapper as it stands, attach a clothespin to it as shown in Fig. 1.4. This will slow the clapper down and will give you a chance to practice using the stroboscope. Try to stop the motion of the clapper and clothespin with four open slits on your stroboscope. To calculate the time of one vibration of the loaded clapper, you may find it convenient to measure the time of twenty rotations of the disc.

Repeat your measurement with all twelve slits open. How can you be sure that your calculations in both cases do not give twice the correct value?

Now you can find the time of one vibration of the bell clapper without the clothespin. By how many orders of magnitude have you extended your ability to measure short times?

By finding the time of one vibration of the clapper, you have calibrated the bell and can now use it to measure short time intervals.

You can use this apparatus as a recording timer to measure the time interval between two handclaps (Fig. 1.5). When the paper tape is pulled through, the clapper will leave marks at equally spaced time intervals. Try several practice runs to make sure that the clapper is marking the paper tape and to determine how fast to pull the paper tape to have the marks adequately spaced for counting. While you are pulling the paper tape

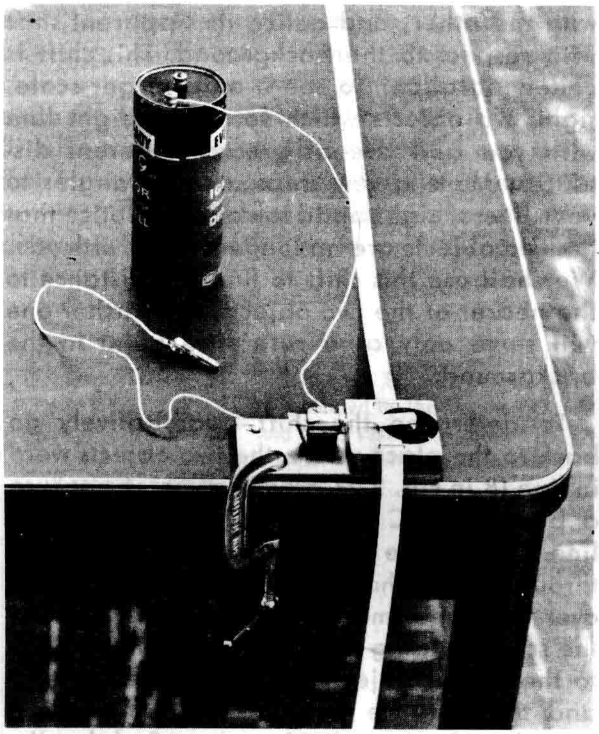

FIGURE 1.5

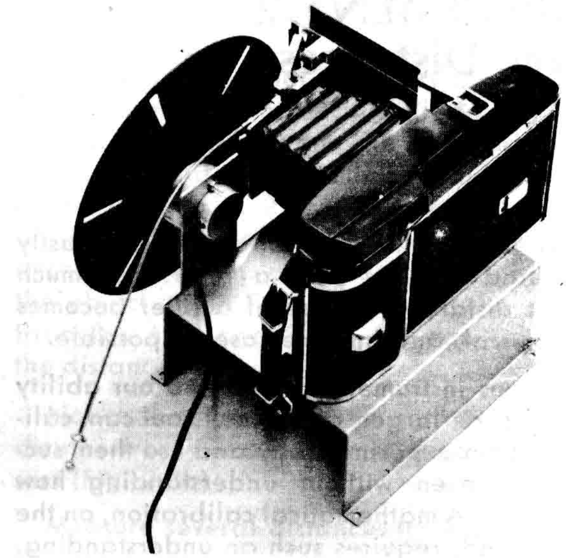

FIGURE 1.6

through the timer, have your partner clap twice. Turn on the timer at the sound of the first clap and turn it off at the second clap. Count the number of marks on the paper tape and determine the time interval between claps.

We cannot "stop" a nonrepetitive motion by viewing it through a stroboscope. However, by counting how many times we see the moving object while it moves from one place to another, we can find how long it takes to move this distance. To facilitate the counting, we can make a permanent record of the motion by photographing it through a stroboscope (Fig. 1.6) or by using the bell timer.

Tie the tape to a small object and measure the time it takes the object to fall from the table to the floor.

How could you use the tape and a watch to calibrate the bell timer?

Compare the time of one vibration measured when the clapper vibrates freely with the time of one vibration when the clapper hits the tape.

EXPERIMENT 2
Large Distances

Distances of the order of a meter are easily measured directly with a ruler. For much larger distances the use of a ruler becomes impractical, and in some cases impossible.

Various instruments can extend our ability to measure larger distances. You can calibrate them experimentally and use them successfully even without understanding how they work. A mathematical calibration, on the other hand, requires such an understanding.

To measure a distance of the order of a kilometer we like to have an instrument simple enough to be calibrated mathematically. The parallax viewer shown in Fig. 2.1 is such an instrument.

To understand what we mean by parallax, look at a pencil first with one eye and then with the other, and notice its apparent shift with respect to the background. This shift is called parallax. To see it on a larger scale, sight two objects which form a straight line with you and are at greatly different distances. Mo e a few steps at right angles to your line of sight and look again. Notice that the two objects are no longer in line with you. We shall use this shift to find the distance to the nearer of the two objects; the farther one will serve only as a reference point in the background.

To determine the shift quantitatively go back to the place where the two objects were in line (*B* in Fig. 2.2). From that point measure a base line *BC* perpendicular to the sight line. At *C* use the parallax viewer and through the pinhole sight the reference point over the center mark of the scale. The record the scale reading that lies on the line of sight to the nearer object. From the scale reading and the distance between the two sighting positions (the base line) you can find the distance to the nearer of the two objects.

Figure 2.2 is a schematic drawing of the

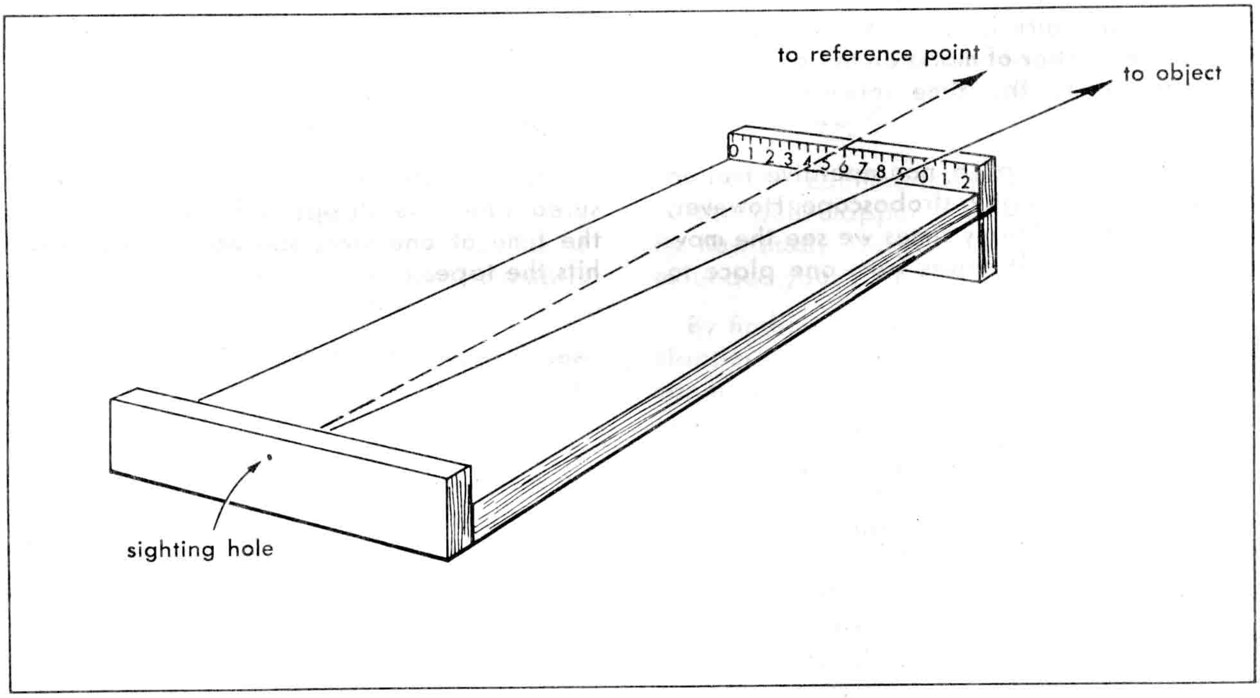

FIGURE 2.1

situation. Note that the angles θ and θ' are not very different. If the reference point chosen is very far away compared with the distance to be measured, θ practically equals θ' and the triangles *BDC* and *OCS* are similar. How can you express the distance *BD* in terms of the length of the base line *BC*, the distance between the scale and the pinhole

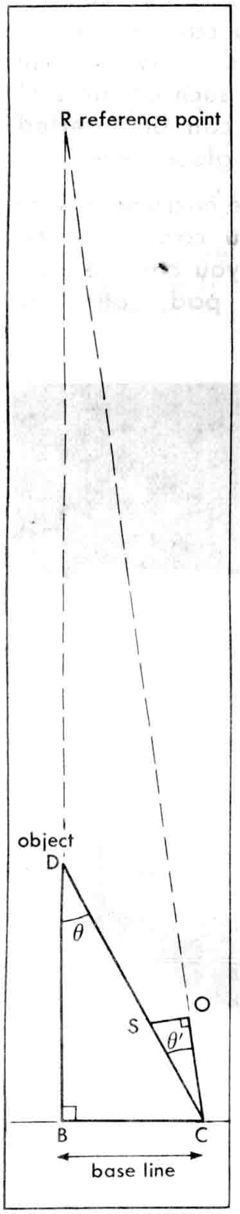

FIGURE 2.2 The size of the viewer as indicated by the lengths CO and OS is vastly exaggerated in comparison with the distances BC and BD.

CO, and the parallax reading on the scale *OS*?

In practice, it is not necessary that the distant reference point be initially in line with the object. You can sight the reference point as before and read the line of sight to the object (S_1 in Fig. 2.3a). Then move at right angles to the direction of the point of reference, sight again, and read the direction of the object (S_2 in Fig. 2.3a). From the similar triangles *ADC* and S_1CS_2 you can calculate the distance *AD*.

Notice that the base line and the perpendicular from the object to it need not intersect (Fig. 2.3b).

Measure several distances to objects in the kilometer range, using different reference points. Which of these measurements do you consider most accurate?

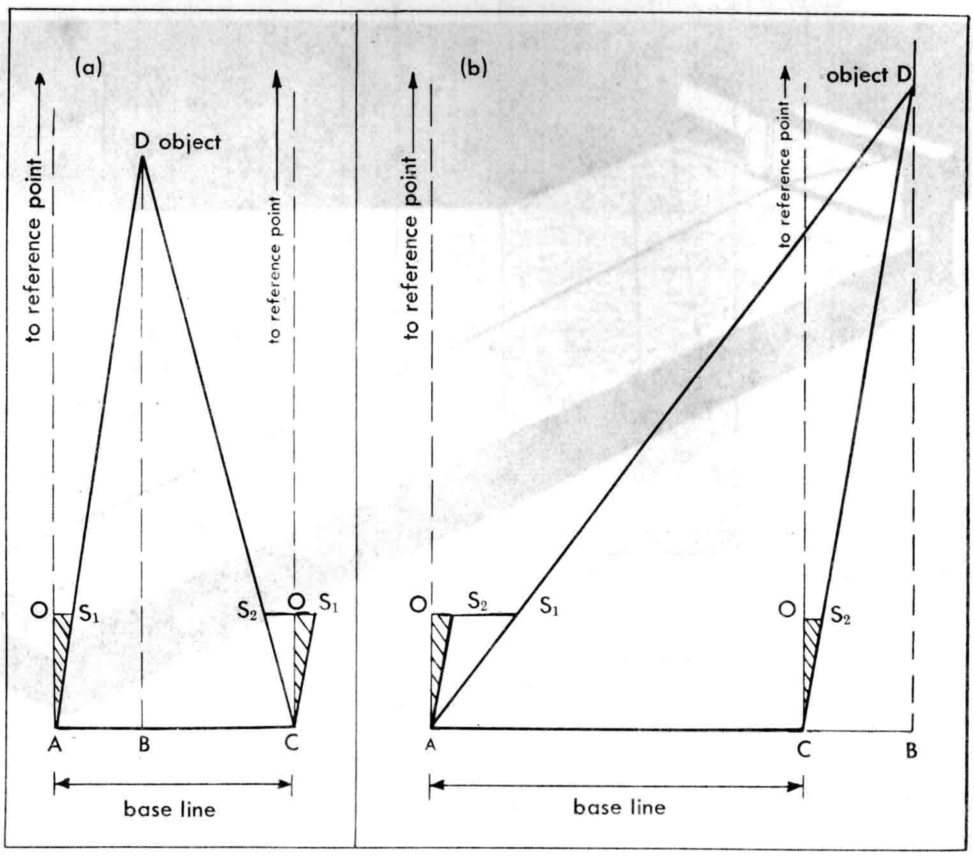

FIGURE 2.3

EXPERIMENT 3
Small Distances

You can measure the thickness of a piece of cardboard with a ruler. For much smaller lengths the readings from the ruler become very inaccurate. Using a ruler to measure the thickness of a hair will only show that a hair is very thin, something you knew before you started. The optical micrometer (Fig. 3.1) permits considerable extension of your ability to measure very short distances.

To see how sensitive it is, hold the micrometer so that you can see the image of the reference pin in the mirror. Now, looking in the mirror, align the thread until it points directly at the reference pin and read the position of the thread on the scale. Insert a single piece of paper between the mirror and the glass plate (Fig. 3.2) and find the new direction in which the thread is aligned with the pin. How does the distance between the two scale readings compare with the thickness of the paper?

The optical micrometer can be calibrated mathematically, but this is rather complicated. It is much simpler to calibrate it experimentally. To do this, you may use thin objects of known thickness, such as wires of specified diameters, which can be inserted between the mirror and the glass plate.

You can also calibrate the micrometer with objects whose thickness you can calculate. For example, with a ruler you can measure the thickness of a writing pad, count the

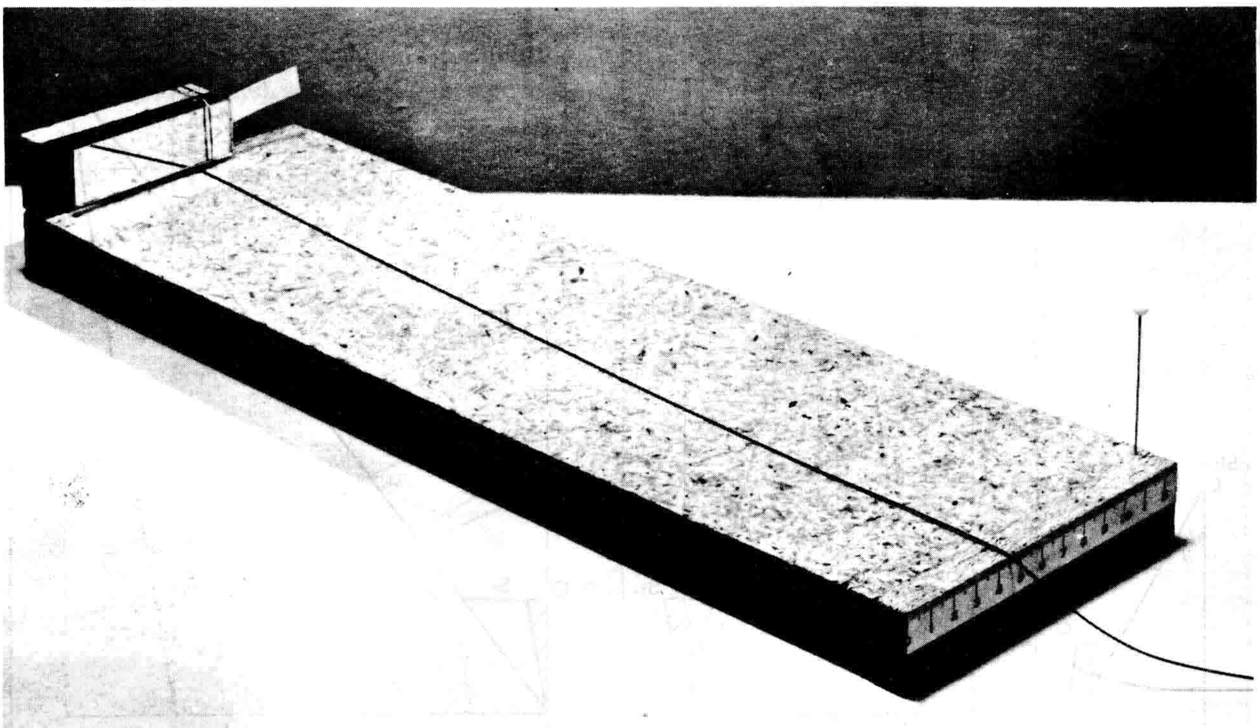

FIGURE 3.1

number of sheets, and calculate the thickness of each. Then insert separate sheets, one by one, and read the position of the thread on the scale to calibrate the micrometer. Repeat each step to see whether your scale readings fall on the same places, and so get an idea of the accuracy of your calibration. Use your micrometer to find the thickness of a hair, a piece of aluminum foil, or a sheet of cellophane.

Press two razor blades together and make a pair of fine, parallel cuts on a piece of paper. Use the optical micrometer to determine the distance between the two cuts. What assumptions have you made?

Make a histogram of your results and those of your classmates to determine the most probable value of the distance between the cuts. You will need this value in Experiment 16.

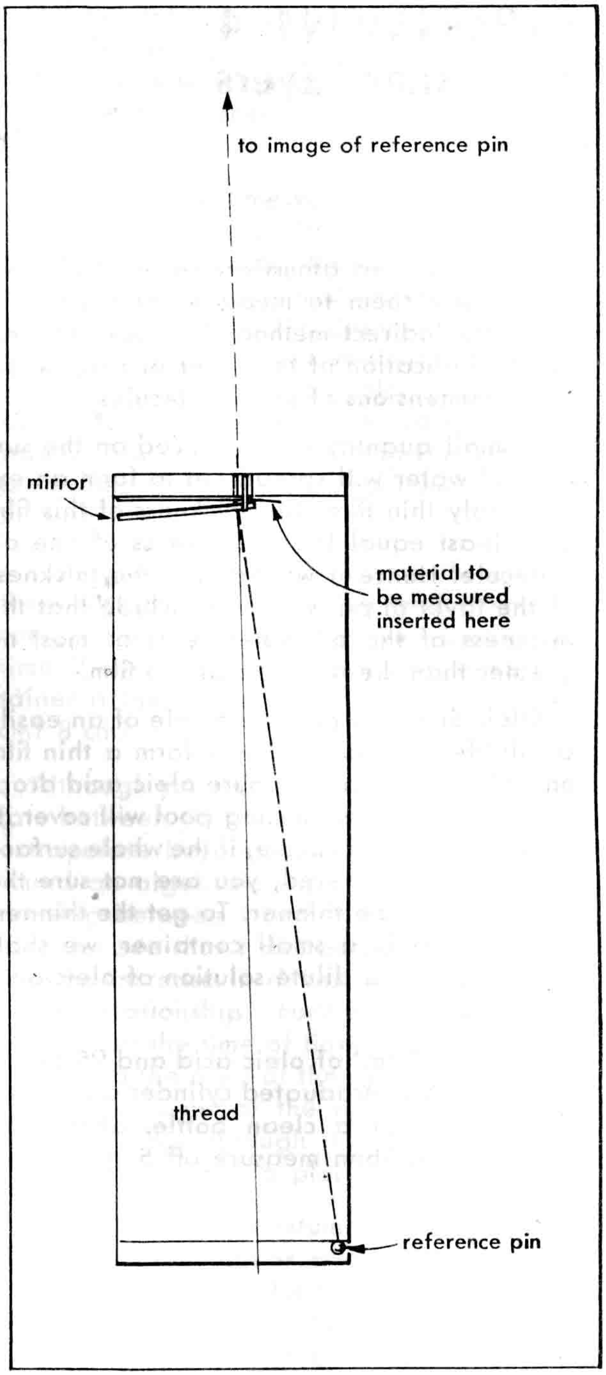

FIGURE 3.2

EXPERIMENT 4
Molecular Layers

Molecules and atoms are so small that we cannot see them to measure their size. By using an indirect method, however, we can get an indication of the order of magnitude of the dimensions of some molecules.

A small quantity of oil placed on the surface of water will spread out to form an exceedingly thin film. The thickness of this film is at least equal to the thickness of one oil molecule. Hence if we can find the thickness of the layer of oil, we can conclude that the thickness of the oil molecule is at most no greater than the thickness of the film.

Oleic acid is a good example of an easily available material that will form a thin film on water. One drop of pure oleic acid dropped into a small swimming pool will cover its entire surface. Of course, if the whole surface of the pool is covered, you are not sure the film could not be thinner. To get the thinnest possible film in a small container, we shall use a drop of a dilute solution of oleic acid in alcohol.

Measure 5 cm^3 of oleic acid and 95 cm^3 of alcohol into a graduated cylinder and place the solution in a clean bottle. Shake the mixture well. Then measure off 5 cm^3 of this solution and mix with 45 cm^3 of alcohol. Calculate the concentration of this solution.

Fill a large, clean, shallow tray with water to a depth of about one centimeter. Dusting the surface of the water lightly with chalk or lycopodium powder will make the film of acid visible. (Chalk rubbed on sandpaper will produce clean chalk dust.)

To make sure the film is caused by the oleic acid and not by the alcohol, first drop one or two drops of alcohol in the tray with the eyedropper. What do you observe?

Now use the eyedropper to apply a drop of oleic acid solution. Measure the average diameter of the film and calculate its area. Do two drops form twice the area of one drop? How about three drops? What conclusions do you draw from your answers?

Find out how many drops of this size there are in a cubic centimeter and, using the volume of the drop and the area of the layer, calculate the thickness of the layer. Estimate the accuracy of this calculation, considering the error introduced in each step.

If the thickness of the layer were magnified to 1 cm, how tall would you be on the same scale?

If the layer is considered to be one molecule thick and the molecules are assumed to be essentially cubes, how many molecules would fill one cubic centimeter?

The density of oleic acid is 0.89 gm/cm^3. What is the mass of one molecule?

EXPERIMENT 5
Analysis of an Experiment

In Table 1 are the results of an experiment. You are asked to present and analyze these results in a form which will enable you to draw conclusions about the nature of the process under investigation and to predict the outcome of similar experiments. The presentation and analysis of experimental results is an essential part of physics.

The experiment was an investigation of the time it takes water to pour out of a can through a hole in the bottom. As you would expect, this time depends on the size of the hole and the amount of water in the can.

To find the dependence on the size of the hole, four large cylindrical containers of water of the same size were emptied through relatively small circular openings of different diameters. To find the dependence on the amount of water, the same containers were filled to different heights.

Each measurement was repeated several times, and the averages of the times (in seconds) that each container took to empty have been entered in the table. Because of the difficulty of measuring short times accurately with a watch, there are fewer significant figures in the measurement of short times than in those of the longer times.

Table 5.1

Times to Empty (sec)

d in cm \ h in cm	30	10	4	1
1.5	73.0	43.5	26.7	13.5
2	41.2	23.7	15.0	7.2
3	18.4	10.5	6.8	3.7
5	6.8	3.9	2.2	1.5

All the information we shall use is in the table, but a graphical presentation will enable us to make predictions and will greatly facilitate the discovery of mathematical relationships.

First, plot the time versus the diameter of the opening for a constant height, say 30 cm. It is customary to mark the independent variable (in this case, the diameter d) on the horizontal axis and the dependent variable (here the time t) on the vertical axis. To get maximum accuracy on your plot, you will wish the curve to extend across the whole sheet of paper. Choose your scales on the two axes accordingly, without making them awkward to read.

Connect the points by a smooth curve. Is there just one way of doing this? From your curve, how accurately can you predict the time it would take to empty the same container if the diameter of the opening was 4 cm? 8 cm?

Although you can use the curve to interpolate between your measurements and roughly extrapolate beyond them, you have not yet found an algebraic expression for the relationship between t and d. From your graph you can see that t decreases rather rapidly with an increase in d; this suggests some inverse relationship. Furthermore, you may argue that the time of flow should be simply related to the area of the opening, since the larger the area of the opening, the more water will flow through it in the same time. This suggests trying a plot of t versus $1/d^2$.

To do this, add a column for the values of $1/d^2$ in your notebook and, again choosing a convenient scale, plot t versus $1/d^2$ and connect the points with a smooth curve. What do you find? Was your conjecture correct? Can you write the algebraic relation between t and d for the particular height of water used?

To find whether this kind of relationship between t and d also holds when the container is filled to different heights, on the same sheet of graph paper plot the graphs of t versus $1/d^2$ for the other heights. What do you conclude?

Notice that the graph for $h = 1$ cm extends upward very slightly. Make a special plot of these data on a larger time scale so that you will use the whole sheet. What do you observe? On the basis of your data, what can you say about the algebraic relation between t and d for $h = 1$ cm?

Now investigate the dependence of t on h when the diameter of the opening stays fixed. Take the case of $d = 1.5$ cm, which is the first row. Make a plot in which h will be marked on the horizontal axis and connect your points by a curve. Extrapolate the curve toward the origin. Does it pass through it? Would you expect it to do so?

How can you use your plots of t versus $1/d^2$ to predict t for $h = 20$ cm and $d = 4$ cm?

• • •

There is no simple geometric consideration to guide us to the right mathematical relation between t and h. You can check to see if the relation belongs to a general class of relations, such as a power law, $t \propto h^n$. To do this, plot log t versus log h (or simply t versus h on log-log paper). What do you obtain? What is the value of n?

Can you find the general expression for time of flow as a function of both h and d? Calculate t for $h = 20$ cm and $d = 4$ cm and compare the answer with that found graphically. Which do you think is more reliable?

EXPERIMENT 6
Reflection from a Plane Mirror

Hold a pencil vertically at arm's length. In your other hand, hold a second pencil about 15 cm closer than the first. Without moving the pencils, look at them while you move your head from side to side. Which way does the nearer pencil appear to move with respect to the one behind it when you move your head to the left? Now move the pencils closer together and observe the apparent relative motion between them as you move your head. Where must the pencils be if there is to be no apparent relative motion, that is, no parallax, between them?

Now we shall use parallax to locate the image of a nail seen in a plane mirror. Support a plane mirror vertically on the table by fastening it to a wood block with a rubber band. Stand a nail on its head about 10 cm in front of the mirror. Where do you think the image of the nail is? Move your head from side to side while looking at the nail and the image. Is the image in front of, at the same place as, or behind the real nail? Locate the position of the image of the nail by moving a second nail around until there is no parallax between it and the image of the first nail. In this way, locate the position of the image for several positions of the object. How do the distances of the image and object from the reflecting surface compare?

We can also locate the position of an object by drawing rays which show the direction in which light travels from it to our eye. Stick a pin vertically into a piece of paper resting on a sheet of soft cardboard. This will be the object pin. Establish the direction in which light comes to your eye from the pin by sticking two additional pins into the paper along the line of sight. Your eye should be at arm's length from the pins as you stick them in place so that all three pins will be in clear focus simultaneously. Look at the object pin from several widely different directions and, with more pins, mark the new lines of sight to the object pin. Where do these lines intersect?

We can use the same method to locate an image. On a fresh piece of paper, locate the position of the image of a pin seen in a plane mirror by tracing at least three rays from widely different directions. Mark the position of the mirror on the paper with a straight line before removing it. Where do the lines of sight converge?

Draw rays showing the path of the light from the object pin to the points on the mirror where the light was reflected to your eye. What do you conclude about the angles formed between the mirror surface and the light paths?

Arrange two mirrors at right angles on the paper with a nail as an object somewhere between them. Locate all the images by parallax. From what you have learned about reflection in this experiment, show that these images are where you would expect to find them.