LABORATORY GUIDE

PSSC

PHYSICS

FIFTH EDITION

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Published simultaneously in Canada.

Printed in the United States of America.

International Standard Book Number: 0-669-03115-1

Preface

As in earlier editions of PSSC Physics, the interplay between experiment and theory is at the heart of the program. And just as before, experimenting means working with hands and head. However, changes in organization and emphasis in the text and changes in the technology of instrumentation had a profound effect on this edition of the Laboratory Guide.

A major effort has been made to improve the quality and cost effectiveness of the equipment with which to carry out the experiments. This will be easily recognized through the many new photographs. Some PSSC "classics" have been replaced. (The tuning eye, used to find the mass of the electron, has been retained for those who still have this piece of equipment.) In addition, we have added three experiments with a simple cathode ray tube (Exp. 19, 22, and 23).

The change in emphasis in mechanics resulted in three new experiments (Exp. 5, 8, and 11). To support the development of the energetics of radiation and the particle model of light, we introduced two new experiments (Exp. 32 and 33). The practical side of electric circuits was strengthened by adding one experiment (Exp. 15). Many more experiments were rewritten for further clarity, and some were deleted.

ACKNOWLEDGMENTS

We are indebted to Professor Alan Portis for drafting the experiments with the cathode ray tube. Our thanks are due to Stephen McKaughan for making major contributions to the design of the new apparatus and constructing the prototypes, and to Edward A. Shore for photographing the new equipment.

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June 1980

To The Student

Physics has been defined as the "purposeful interrogation of nature." The laboratory part of the PSSC program provides you with the means for this interrogation.

This Guide will explain the purpose of each experiment and give you some technical hints, but the thinking and doing will be left to you.

Throughout this Guide you will find many questions. Finding the answer to these questions may sometimes require a little thought about what you have done before, or it may require a short calculation. Sometimes more experimentation will be called for. It is up to you to decide what to do in each case.

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

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

Many of these experiments 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 going at it alone.

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

The apparatus used in many experiments is quite simple. You can make many items yourself and experiment further at home.

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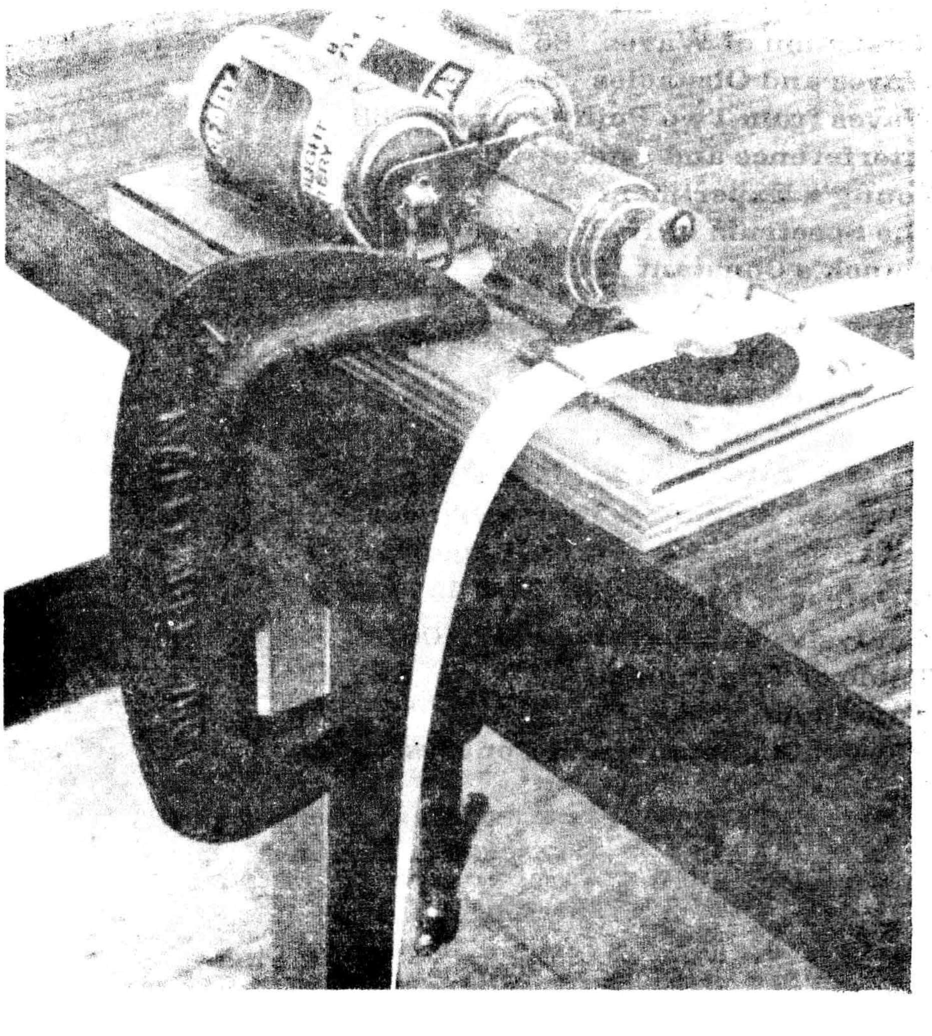
1

Motion: Velocity and Acceleration

Studying the motion of an object requires a record of the object's position at different times, preferably at regular time intervals. With such a record you can study quite irregular motion—for example, the motion of your hand while you walk. Such an irregular motion is particularly suited to demonstrating the relation between the graphs of position, velocity, and acceleration as a function of time.

Set up the timer as shown in Fig. 1-1. Grasp the end of the tape in your hand and walk several steps, swinging your hand freely as you pull the tape, while your partner operates the timer.

Figure 1-1

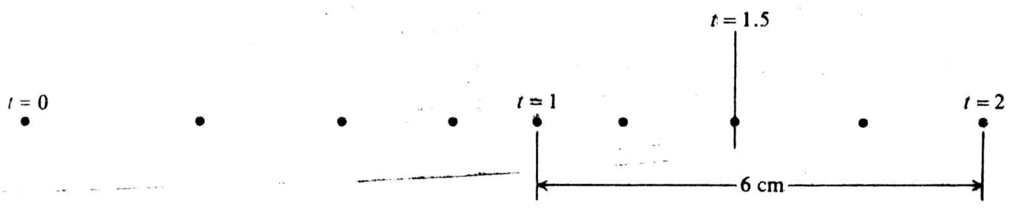


- If you choose the time interval between two consecutive marks as a unit of time, a "tick," what does the distance between any two adjacent marks represent?
- From an inspection of your tape, can you find where your velocity was highest? Where it was lowest?

Starting at any point near the beginning, plot a graph of position versus time. Since a tick may be too small a unit of time, it will be more convenient to use 4 ticks (which you can call a "tock").

You can also obtain an approximate velocity vs. time graph directly from the tape by plotting the average velocity over a one-tock interval as a function of time. This average velocity is an approximation of the instantaneous velocity at the middle of the interval. For example, the average velocity between time $t = 1$ and $t = 2$ in Fig. 1-2 is 6 cm/tock. This is an approximation of the instantaneous velocity at $t = 1.5$ tocks.

Figure 1–2



You can check this approximation at a few points by finding the slope of position vs. time graph at corresponding points.

- How closely do they agree?

From your velocity vs. time graph, plot the position vs. time by measuring the area under the curve as a function of time.

- How do the positions found this way compare with the positions measured directly on the tape?
- Looking again at your tape, can you guess where the acceleration was greatest? Where it was smallest?

From the plot of velocity vs. time, make a plot of acceleration vs. time.

- How good was your early guess as to the times of the greatest and the smallest accelerations?

2

Changes in Velocity with a Constant Force

You know qualitatively from everyday experience that you must apply a force to move an object from rest or to change its velocity while it is moving. You can now investigate the quantitative relation between the velocity changes and the force.

The experiment is best performed on a smooth, level table. If necessary, level the table with wedges under the legs and check with a spirit level. Crumbly bricks may be wrapped in aluminum foil or wrapping paper to keep their grit from getting on the table. Be sure that the stop is securely clamped at the end of the table.

Before making runs to find how the velocity changes with a constant force, you should be sure that the cart moves with a nearly constant velocity when you do not pull it. Load the cart with two bricks and make several tapes with the timer, giving the cart different initial pushes. Look carefully at the tapes.

- Is the velocity more nearly uniform when the cart moves slowly or when it moves rapidly?

The cart, loaded with bricks and running on roller skate wheels, can be pulled forward with a constant force by hand. To make sure this force is constant, we apply it through rubber strands which are kept stretched at a constant length as the cart is pulled along (Fig. 2-1).

- Why does the student pulling the cart in Fig. 2-1 not touch it?

As it moves, the cart pulls a strip of paper tape under the striker of an electric timer clamped to the table edge. From these tapes you can then find the velocity at different points on a run and can plot a curve of the velocity of the cart as a function of time.

Now you can study the effect of a constant pull on the motion of the cart. Attach one end of a rubber loop to the cart as shown in Fig. 2-2. Hook the other end of the rubber loop over the end of a meter stick. While your partner holds the cart, extend the meter stick forward alongside the cart until the rubber loop stretches to a given total length—say 80 cm. Your partner starts the timer and a few seconds later, on signal, releases the cart. You move forward, pulling the cart while keeping the rubber strands stretched to the 80 cm mark. You will find it worthwhile to make a few practice runs.


Figure 2–1

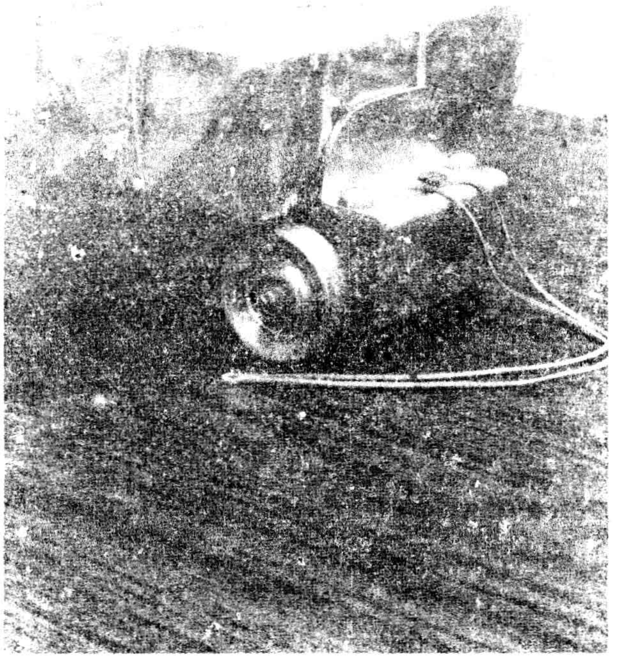


Figure 2–2

Now attach the paper tape to the cart loaded with two bricks and run off a tape. If you could not keep the rubber stretched to a constant length towarc' the end of the run, discard the last part of the tape. From this tape, plot a graph of the velocity as a function of time (see Experiment 1). It is not necessary to use all the marks on the tape in calculating the velocity. Instead, use groups of ten marks for a convenient unit time interval, measuring the velocity in meters per ten "ticks." Analyze only that portion of the tape which represents the part of the run where you are reasonably sure the force you applied was constant.

Run off another tape, using four bricks on the cart and the same rubber loop. Plot the data from this tape on your original graph.

- What do you conclude about the acceleration produced by a constant force?
- Is the force you exert the only force acting on the cart?
- Was the acceleration greater or smaller when a larger mass was accelerated?

3

The Dependence of Acceleration on Force and Mass

The acceleration produced by a constant force was the subject of the preceding experiment. Now you can investigate quantitatively how different forces accelerate a given mass and how a given force accelerates different masses.

Acceleration Caused by Different Forces

Using one, two, three, and four rubber loops to produce the accelerating force, make tape recordings of the motion of the cart when it is loaded with four bricks. A few practice runs with each force will be useful. Find the acceleration from the tapes and plot a graph of acceleration as a function of the force, that is, the number of loops.

Since you know from the last experiment that the acceleration is constant for a constant force, it is not necessary to calculate the acceleration for many different intervals in the same run. Find the acceleration from the change in velocity during two equal time intervals. It may be wise to include neither the start of the tape, where the data cannot be resolved, nor the last part of the motion, where it is difficult to keep the force constant.

- What do you conclude from your graph?
- What can you say about the ratio of force to acceleration in this part of the experiment?
- Assuming no friction in the apparatus, should the graph pass through the origin?
- Where, with respect to the origin, would you expect your graph to pass?

The Effect of Mass on the Acceleration Produced by a Constant Force

With one rubber loop find the acceleration of the cart when it is loaded with one, two, three, four, and five bricks. Plot a graph of the ratio of force to acceleration as a function of the number of bricks.

- What do you conclude from your graph?
- From your graph, can you express the mass of the cart alone in terms of the mass of the bricks?
- How could you find the mass of a chunk of lead or of a heavy stone, using this apparatus? Try it.

4

Inertial and Gravitational Mass

The inertial balance, a simple device for measuring the inertial mass of different objects, is shown in Fig. 4-1. Put different quantities of matter on the platform and qualitatively observe the periods of vibration of these masses. (The period is the time of one complete vibration.)

- Is the period greater or smaller for larger masses?

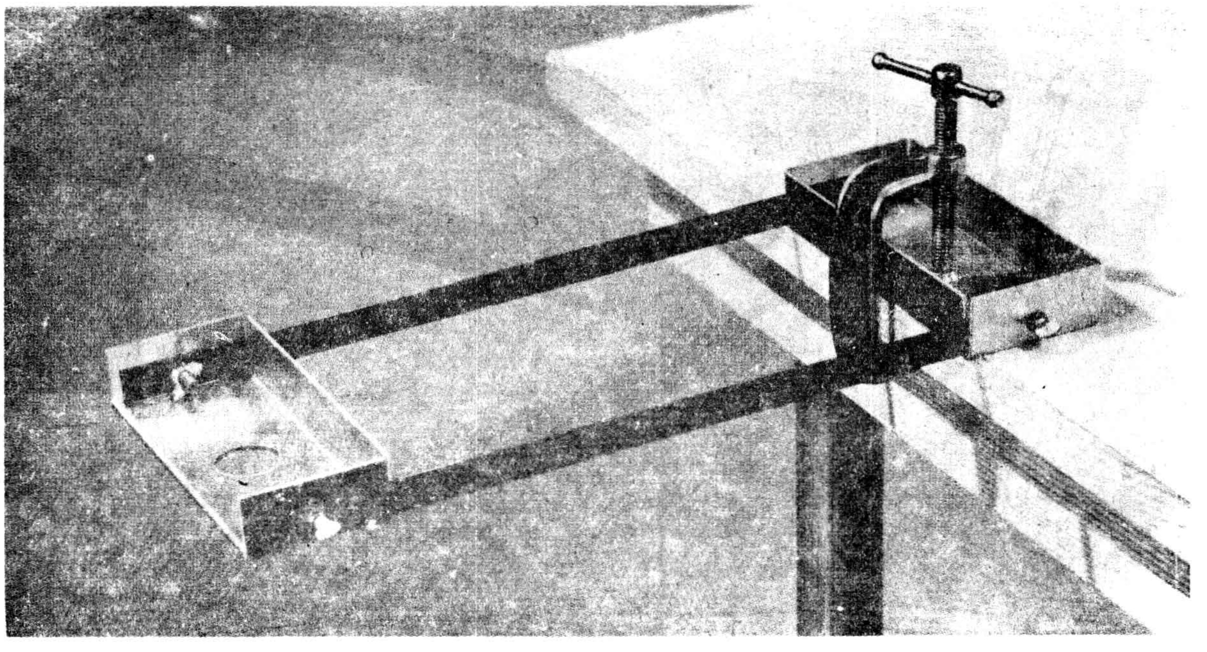


Figure 4–1

Find the quantitative relationship between the quantity of matter on the balance and the period of vibration by plotting a graph of the period as a function of the mass. You can do this in the following way:

First, measure the period of the balance alone by measuring the time for as many vibrations as you can conveniently count. Since the period of the balance is very short, it is difficult to count the vibrations visually. Hold a small piece of paper near one of the steel strips and count the audible snaps made by the paper when the blade just ticks it. It may be easier to count in groups of three or four vibrations.

Select six nearly identical objects or unit masses such as C clamps. Now measure the period of the balance loaded with each of the six C clamps (Fig. 4-2).

- How many vibrations should you time and for how many seconds should you time them to make sure that your error is no greater than about 2 percent?

Now find the periods with one, two, three . . . unit masses on the balance and from these data plot the period as a function of the mass (number of clamps) on the balance. You have now calibrated your inertial balance.

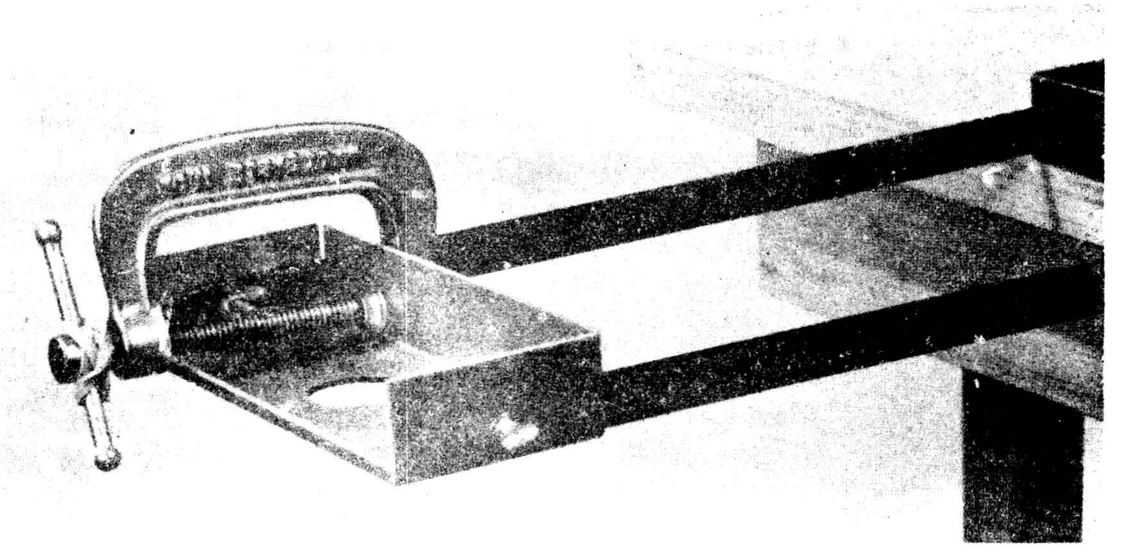


Figure 4–2

- How can you use the balance to find the *inertial* mass of, say, a stone?

You can find the *gravitational* mass of each of the clamps by using an ordinary laboratory balance.

- To within what percent do they have the same gravitational mass?
- What do you predict for the *gravitational* mass of the stone from your previous measurements? Check your prediction by finding the gravitational mass on an ordinary laboratory balance.
- If you had found similar results with other objects, what would you conclude about gravitational and inertial mass? Are they equal? Proportional? Independent?
- Must the units of inertial mass be the same as those for gravitational mass?
- How would the results of this experiment differ if you did the experiment on the moon?

To check whether or not gravity plays a part in the operation of the inertial balance, load it with the iron slug. This can be done by inserting a wire through the center hole of the slug and setting the slug into the hole in the platform. The slug then rests on the platform. Measure the period of the loaded balance.

Now lift the slug slightly so that its mass no longer rests on the platform and hold it in this position by a long thread tied to a ringstand (Fig. 4-3).

- How do the periods compare in these two cases?
- Is gravity relevant here?

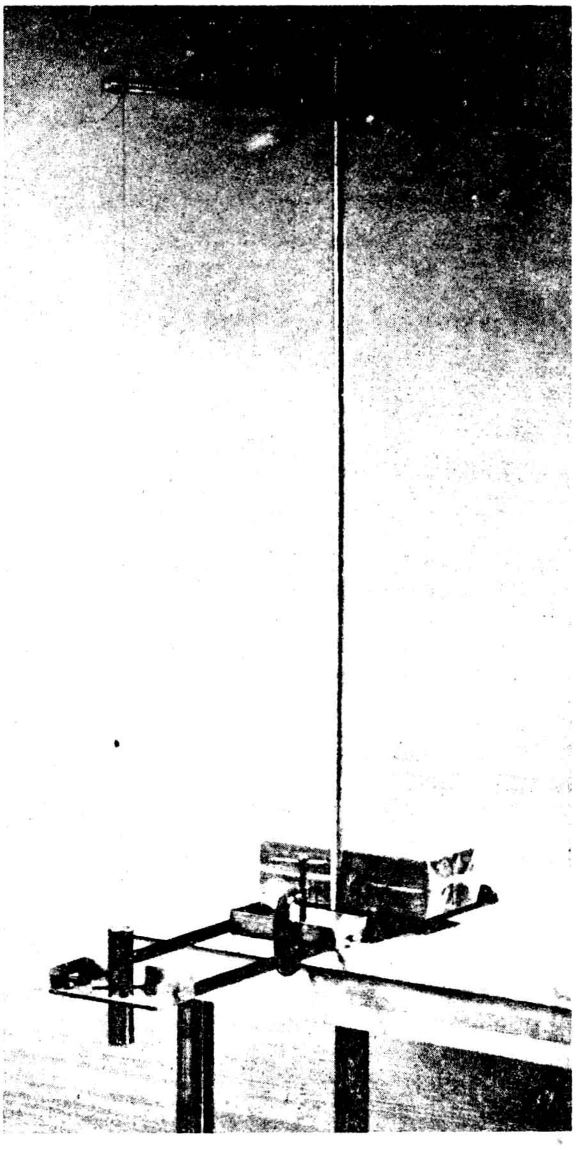


Figure 4–3

5

Forces Acting at an Angle

Suppose a rubber band stretched a certain amount gives a cart an acceleration a. You know from previous experiments that two such rubber bands in parallel would give the cart an acceleration $2a$.

- What do you predict will be the acceleration of the cart if the rubber bands are stretched the same amount but at angles of 45° to the axis of the cart (Fig. 5-1)?

Figure 5–1

Check your prediction. First make a run with a single rubber band along the axis of the cart. You can fix the stretch of the band by holding a stick between the two sides of the band. Stretch the band 3–4 cm beyond the free end of the stick. Mark the position of the free end of the stick by putting an ink mark on the stretched band next to the free end of the stick. Make a tape for each rubber band stretched by the same amount. This will allow you to determine how well the bands are matched.

Short lines are scratched on the cart to help you and your partner maintain angles of 45° to the axis of the cart during the next runs. Make a few practice runs to insure that you get the knack of keeping the rubber stretched by the correct amount and at the correct angle before making a tape for each member of the team.

- From the analysis of the tapes, what do you conclude about the net effect of two equal forces acting on the cart at an angle of 90° to each other?

- What do you predict would be the effect of two equal forces acting on opposite sides of the axis of the car, each at an angle of 60° to the axis?

Write an expression for the net force when the cart is acted on by two equal forces, each making an angle α with the axis of the cart on opposite sides.

6

Centripetal Force

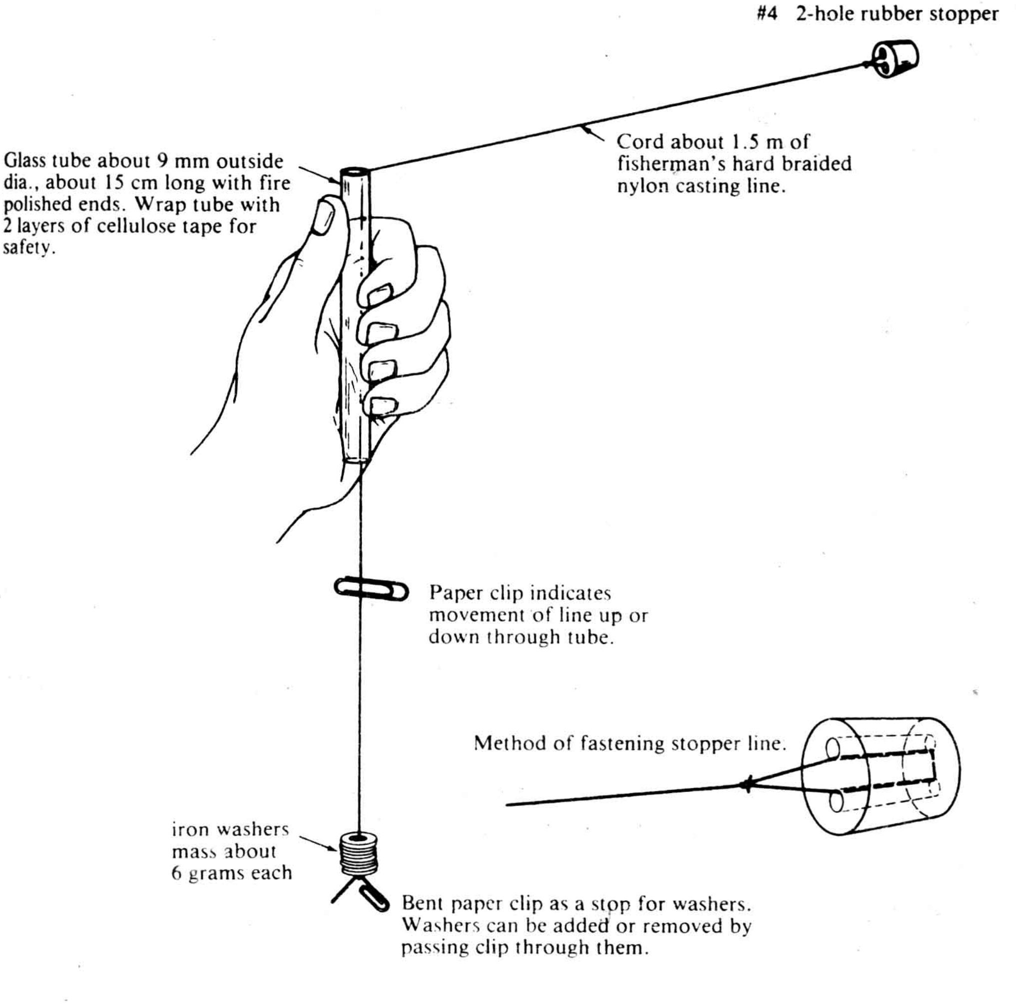
In Section 3-10 of the text we saw evidence that Newton's law holds for circular motion just as it holds for motion on a straight line. Specifically, we claimed that the magnitude of the centripetal force needed to keep a mass m moving in a circle of radius R with a period T is given by

$$F = \frac{m4\pi^2R}{T^2}$$

The purpose of this experiment is to check this relation for several values of R and T. In the process you will also learn some general methods of searching for mathematical relationships that will be useful in later experiments.

The equipment that you will use is shown in Fig. 6-1. It allows you to measure the force while observing the motion. When the glass tube is swung in a small circle above your head, the rubber stopper moves around in a horizontal circle at the end of a string. The string is threaded through

Figure 6–1



the tube and fastened to some washers hanging below. The force of gravity on these washers, acting along the string, provides the centripetal force needed to keep the stopper moving in a circle. Before taking any measurement, get a feel for the apparatus. With only one washer on the end of the string to keep the stopper from getting away, whirl the stopper over your head while holding onto the string below the tube.

- Do you have to increase the pull on the string when you increase the speed of the stopper?
- What happens if you let go of the string?

The mass of the stopper will remain constant throughout the experiment. Pull enough string through the tube to allow for a radius of about 1 m. A paper clip attached to the string just below the tube will serve as a marker to help you keep the radius constant. (The paper clip must not touch the bottom of the glass tube.) Once you have set the clip, measure the radius accurately from the center of the stopper to the top of the tube. Six or more washers hung on the end of the string will provide an adequate centripetal force. Before any measurements are taken, practice swinging the stopper so that it revolves in a horizontal plane.

To find the period of revolution of the stopper, have a partner measure the time and count the number of revolutions while you swing the stopper around. From the time and number of revolutions, calculate the period.

Repeat the experiment with larger numbers of washers and make a table of the various values of F (in newtons) and T (in seconds).

Here are two ways of comparing your data with the derived formula. If the formula is valid, then the product FT^2 should be constant for all values of F, and equal to $4\pi^2 mR$. You can calculate the value of FT^2 from your table and see how close they are to their mean value.

You can also calculate $\frac{1}{T^2}$ for each value of F, and plot F as a function of $\frac{1}{T^2}$. (That is, you plot $\frac{1}{T^2}$ on the horizontal axis.) If the formula is valid, the graph of

$$F = 4\pi^2 mR \cdot \frac{1}{T^2}$$

will be a straight line through the origin. The slope of the line will be $4\pi^2 mR$. Choose either way to compare the data with the theory.

- If you chose to use the mean value of FT^2, within what percent of $4\pi^2 mR$ is the mean value you obtained?
- If you chose to plot F as a function of $\frac{1}{T^2}$, within what percent of $4\pi^2 mR$ is the slope of the graph you plotted?

For different values of the radius, the product FT^2 should be proportional to the radius. Check this conclusion by taking a few measurements with different radii and plot FT^2 versus R.

- Within what percent of the theoretical value of the proportionality constant is the proportionality constant you have found?