There are situations in which physics students would profit from the performance of real quantitative experiments but the equipment is lacking, expensive, or too bulky. One such situation is in distance education courses, where the desire to have students perform real experiments is outweighed by cost and/or logistics. The result often is a resort to simulated experiments, or incurring the expense of bringing students to a central location for a marathon session of lab exercises, many of which are done out of sequence. I describe here five quantitative experiments designed for an introductory DE course in physics, that require almost nothing in the way of equipment except a computer and items commonly found in the home.

The physics department of the University of Guelph, in common with others, has for many years offered an introductory physics course as a make-up for those entering the university in science studies but without the senior course in high school physics. The objective of this noncalculus course, therefore, is to establish a sufficient base of largely classical physics and permit the students to progress to the university physics course with some confidence and assurance of success.

About 10 years ago it was also decided to offer this course through distance education, and a study guide was written for this purpose. As the students could not attend the university, a rather elaborate and costly lab kit was assembled with written and videotaped instructions.

It has to be acknowledged that this course, to put it mildly, has not been a success, with drop-out and failure rates running to 80%, while the lecture version has fulfilled its objectives. It was decided, therefore, as a last chance, to make the effort to mount this course as an interactive web-based course.

Initially it was thought that the laboratory section would have to be entirely in the form of simulated experiments, of which there are many available. However, further consideration suggested that there might be meaningful experiments that could be done with simple apparatus and the simulated exercises kept to a minimum. The challenge became to find a way of doing meaningful quantitative experiments in elementary physics using mostly materials that the student could reasonably find in his normal household or purchase

Fig. 1. The equilibrium of three forces using “soda straw pulleys.” The weights (in jumbo paper clips) are from left to right 3, 2, 4.
easily and cheaply. I interpret the contents of a “nor-
mal household” in the broadest sense and include a
computer in the list.

The exercise proved to be an illuminating one,
and several good lessons were developed although the
stricture of “no special apparatus” was relaxed a bit in
one case where the exercise was impossible without it.
It is also interesting that certain branches of elemen-
tary physics seem to me to be intractable to this
approach.

Of course this topic has been addressed previously
in various articles, even in this journal. Many elegant
ideas are collected in that excellent book String and
Sticky Tape Experiments. However most of those ex-
periments require considerable construction on the
part of the student and I wished to avoid that. In what
follows, I will describe several experiments that were
designed or adapted, which more or less conform to
the stated criteria. Some approaches are, I think, new
and others are slight variations of old favorites.

**Equilibrium of Forces (Addition of Vectors)**

An experiment to add three or more force vectors is
common in elementary physics courses. The usual
apparatus is a vertical board upon which drawing
paper is pinned and, with the aid of pulleys and string,
a point is placed in equilibrium. The only “uncom-
mon” parts of this apparatus are the pulleys, whose
purpose is to eliminate friction; a simple substitute for
these was easy to find.

Figure 1 is a photograph of the apparatus that was
decided upon. In place of the pulleys, two plastic soda
straws are used. They are taped to the top of a table
and extend about 8 or 10 cm from the edge; they are
placed about 15 cm apart. Also taped to the edge of
the table and hanging vertically is a sheet of ordinary
note paper. Jumbo paper clips are used for the hang-
ing weights and common sewing thread for string
(black is best). The string and weight assembly is hung
about 1 to 2 cm in front of the note paper.

To eliminate friction it is only necessary to gently,
and simultaneously, pluck the ends of the soda straws
two or three times; the equilibrium point will move to
a final resting place. If the string is placed too far out
on the straws, the amplitude of the plucking motion
produces too much disturbance of the equilibrium
system. Close to the edge, however, produces just
enough motion to largely eliminate the friction. This
latter point can be verified by moving the equilibrium
point away and plucking the straws again. The equi-
librium point will move back to its former position.

Once the frictionless position has been achieved,
the string assembly can be carefully pushed back
against the paper, the configuration traced, and the
usual analysis carried out. Careful elimination of the
friction can produce a vector sum correct to within
a few percent. It should be noted that plastic soda
straws work best. The waxed ones are too sticky.

**Centripetal Force**

This basic experiment is well known (see experi-
ment 1.32 of Ref. 1) and in this discussion only a few
refinements will be mentioned as well as the problem
of timing. The apparatus consists of a thin tube with
a thread (white is best) running through it with a
small mass on the upper end and a larger one on the
lower. By moving the tube rhythmically in a small
circle, the small mass can be made to swing in a large,
early horizontal circle, and equilibrium is established
between the swinging mass and weights hanging on
the lower end of the string. It turns out that there are
many household items that can be used for the tube,
most commonly the plastic cap from a ballpoint pen.
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Free Fall

In this experiment the computer is again used as a timing device; however, the times are far too short to use the stopwatch program. Instead the computer is used to record the sound of a coin dropped from a fixed height onto a hard floor. Also a sound must be produced at the beginning of the drop. A computer with a sound card and microphone are required for this experiment. As a result it may be better suited for classroom use than at home, as not all home computers are equipped with microphones.

The apparatus is shown in Fig. 2. A strip of newspaper about 2 in wide and 6 in long is held tightly with two hands. A large coin is placed at one end of the strip. (The Canadian $2 coin is perfect for this.) The sound recording is started and the strip is given a sharp blow near the center with the edge of a ruler to break or release one end of the strip. It is the sound of this blow that provides $t = 0$. The end of the free fall is the first sound of the coin hitting the floor. Taped to one edge of the paper strip is a plumb bob made from common thread and a 25-cent piece for the bob. In this way the person holding the strip can hold it accurately a fixed distance above the floor. Several strips and bobs can be made up in advance, for example, $\frac{1}{2}$, 1, 1½, and 2 m in length.

Recording and analyzing the sound requires special software. A microphone and appropriate recording and playback software is standard on Macintosh computers and on most modern laptops. PCs are now almost universally equipped with a sound card but a microphone is an extra. The Microsoft operating system provides a program called “Sound Recorder,” which gives 60 seconds of recording time, more than enough for each measurement.

The result of the recording is a .wav file that must be analyzed. The analysis requires some proprietary software designed to analyze at least the temporal properties of a sound file. There are, in fact, a large number of programs available in shareware and even...
Conservation of Momentum

The almost elastic collision of two coins is an excellent example of the conservation of momentum. What a shame that there isn't a method of easily measuring the velocity of a flicked coin. Although measuring the speed is difficult, controlling the direction is rather easy. Therefore, an experiment can be devised that can measure the conservation of momentum in one direction, i.e., transverse to the initial direction of motion of the coin. The direction is controlled by flicking the coin out of a small paper chute. The best coins to use are nickels as they have smooth edges and are sufficiently thick. Pennies have a tendency to ride up over each other.

A piece of heavy paper is laid out as shown in Fig. 4. When folded as shown in Fig. 5, it is taped at one end of a sheet of note paper on which a center line has been drawn as shown in Fig. 6. The center line of the chute must be matched carefully with the center line of the paper.

One nickel is placed just beyond the end of the chute, carefully matched to the center line, and a circle drawn around it with a sharp pencil (Circle 1). A simple experiment at this stage is to shoot a nickel at this "target" and observe that the target always stops on or very near the center line and that the "shooter" intrudes very little into the target circle. The amount of intrusion is an indication of the nonelasticity of the collision.

Next the target is placed off-center and its position drawn (Circle 2) in contact with Circle 1. Flick the shooter with various speeds until a good separation of final positions is achieved as shown in Fig. 6. Record the final positions. Since we do not know the input speed, we can do nothing about momentum conservation along the center line, but the momentum perpendicular to this direction can be measured. Using the friction law, we know that the initial speed is proportional to the square root of the displacement, so a center-to-center measurement of initial and final positions is all that is required for the speeds. By measuring the angles, it is not difficult to verify that the transverse momentum is conserved to 2% or less. More advanced students can also investigate the sum of the two angles and its dependence on the friction between the nickels on contact. It is also instructive for students to carry
out several subsequent collisions and observe that the coins always end up on or near the same lines.

**Diffraction of Light**

The use of a CD to demonstrate diffraction is of course known to all physics teachers. It can also form an essential part of a quantitative experiment. By tapping a right-angle cardboard gusset into the CD case, we have a convenient holder for the grating if the CD is turned outward, instead of the usual inward, on the spindle as shown in Fig. 7. For this experiment the rigorous requirement of no special equipment was relaxed and the students were supplied with a small key-ring laser. These are sufficiently inexpensive in bulk (around $1 Canadian) that it was not felt worthwhile having them turned in, so they were retained by the students as souvenirs of the course. The switch on these lasers does not have a permanent “ON” position, but a spring clothes pin will keep the switch depressed and also makes a handy stabilizing mount. The grating mount and the laser are placed on piles of books and adjusted in height until the laser beam strikes the horizontal diameter of the CD, as this is the only place where the grating lines are vertical. By making sure that the back reflected beam is perpendicular to a wall, then the distance between the first-order diffractions and the distance from the grating to the wall can be determined with a tape measure. Using a figure of 1.6 x 10^-3 mm for the grating spacing, the wavelength of the laser light can be determined.

**Conclusion**

The objectives set out in the beginning have been largely realized. It is possible to devise quantitative experiments in elementary physics that do not require specialized laboratory equipment. Of course some of the functions of laboratory equipment are provided by the personal computer, but the ubiquity of the PC and sophisticated software is a present-day reality that might as well be exploited. It was further hoped that a reasonable accuracy might be achieved with these experiments and that has also been realized; the precision compares with, or even exceeds that, realized by students using conventional laboratory equipment. It will be noticed that there is a glaring lacuna in the list of experiments—there is no electricity exercise. It seems to me that you can’t do electricity without at least one meter, and as these are not common household items, I see no way to fill this gap. Of course the computer can be used with the proper interface, but that is out of the question in the context of this exercise. I place this problem before the readers as a challenge.

**References**

2. In a previous home experiment we have supplied a fire-polished glass tube that was taped for safety. Others have used the siphon tubes from water closets. See Aaron McAlexander, “Physics to go,” *Phys. Teach.* 41, 214–218 (April 2003).
3. The soda straw used in the version of Ref. 1 exhibits considerable friction where the thread runs over the edge of the straw. The molded plastic ends advocated here have much less friction.
4. The “Audacity” sound editor is freeware and available for download at http://audacity.sourceforge.net. It can also be used to record the sound.
6. This is the industry standard and is adhered to with great precision.

**PACS codes:** 01.50P, 01.50H

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