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III. To find the dependence of frequency on the linear density, when the length and tension were constant, each of the three strings had 16 pounds tension applied. The length of one was varied until the string was tuned to a frequency of 256 vib/sec. Then using this same length for each of the other two strings, the frequency of the oscillator was varied until a stable elliptical pattern resulted on the oscilloscope screen. The corresponding frequencies were read from the calibrated dial of the oscillator. Table III shows some typical data. As the data show, the accuracy is in the neighborhood of 1.5 percent, which is much better than could be obtained by the average student by the beat method of tuning.

With the apparatus used here, the chief error was in setting the spring balances at the end of the wires to the correct tension. A sonometer using weight pans and pulleys to supply the tension might possibly increase the accuracy of the results. However, taken as a whole, the experiment was very successful in teaching the laws of vibrating strings to our class in Liberal Arts Physics.

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Use of Motion Pictures in Laboratory Dynamical Studies

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IN student laboratory experiments in dynamics, as, for example, Newton's second law of motion or the conservation of momentum, it is, of course, highly desirable to allow motion with the least possible constraint and to observe the displacements of moving parts without using perturbing markers. This circumstance has led us to use motion pictures in the student laboratory for quantitative observation of rapid dynamic processes, a technique which is used in a well-known textbook.¹ The photographic method combines maximum freedom of movement with accurate observation of position as a function of time, if the camera frame speed is sufficiently high.

A double pendulum apparatus, with which we have studied the conservation of momentum in the student laboratory, is shown in Fig. 1. It consists of two wooden blocks, each suspended by a steel rod from a common free-swinging pivot and counterweighted in such a way that the center of mass of each pendulum is at the center of its wooden block. A spring is compressed between the two blocks, and they are tied together with a thread. When this thread is burned, the pendulums recoil. The mass of each block can be varied at will.

The motion is photographed with a motion picture camera at 64 frames per second. The camera used in this work was a war-surplus gun-point aiming camera, adapted only to the extent of adding a viewfinder. Since there is a coordinate screen behind the pendulums, the student can determine the heights to which the blocks rise by examining the film with a magnifying viewer.

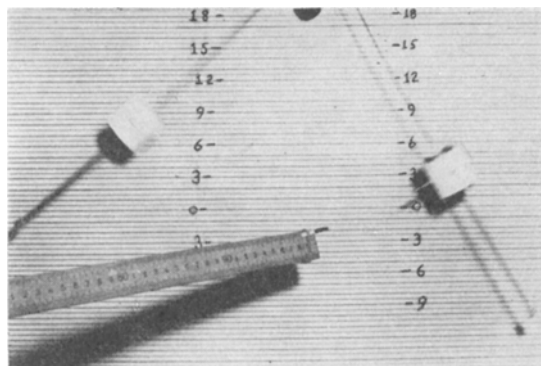


FIG. 1. A frame from movie film of the recoil pendulums flying apart after the burning of the binding thread. In this frame the pendulums are not near the end of their swing and are not completely stopped by the camera. The numbers are retouched for clarity in reproduction; they show clearly in the original.

Since each pendulum receives the same impulse, the initial angular momenta are equal, giving

$$(I_1 + M_1 r^2) \omega_1 = (I_2 + M_2 r^2) \omega_2. \quad (1)$$

Here ω_1 and ω_2 are the initial angular velocities of the two pendulums, I_1 and I_2 are the respective moments of inertia about axes through the centers of mass parallel to the actual axis of rotation, M_1 and M_2 are the respective total masses, and r is the common distance from each center of mass to the axis of rotation. By the conservation of energy we have

$$\begin{aligned} \frac{1}{2}(I_1 + M_1 r^2) \omega_1^2 &= M_1 g h_1, \\ \frac{1}{2}(I_2 + M_2 r^2) \omega_2^2 &= M_2 g h_2, \end{aligned} \quad (2)$$

where h_1 and h_2 are the respective heights to which the centers of mass rise. Combining Eqs. (1) and (2), we find

$$\frac{h_1}{h_2} = \frac{M_2 (I_2 + M_2 r^2)}{M_1 (I_1 + M_1 r^2)}. \quad (3)$$

The moments of inertia I_1 and I_2 can be calculated from the geometry of the pendulums; or if they are constructed such that $I_1 \ll M_1 r^2$ and $I_2 \ll M_2 r^2$, then Eq. (3) reduces

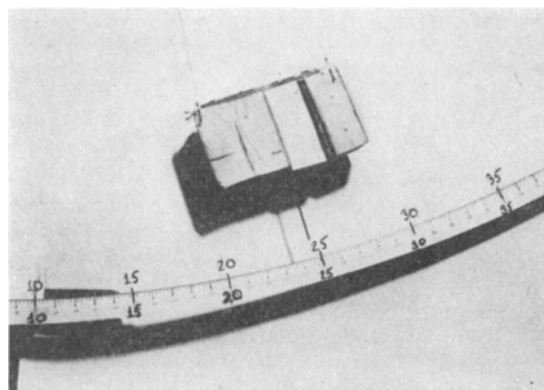


FIG. 2. A frame from movie film of a ballistic pendulum recoiling after being struck by a bullet. The numbers are retouched for clarity in reproduction; they show clearly in the original.

to

$$h_1/h_2 = M_2^2/M_1^2. \quad (4)$$

The student may use his data to verify this prediction.

One may also obtain the initial kinetic energies from Eq. (2), and thus study the sharing of energy in recoil. Agreement with expected results, to within about one percent, is obtained.

Another laboratory study to which motion picture photography lends itself is the measurement of rifle muzzle velocities with the ballistic pendulum. Although keenly interesting to most students, this experiment is often considered too dangerous for class work; the probability of a serious accident is never negligible. However, if the experiment is photographed beforehand by the instructor, the student may study the film in safety. Figure 2 is a sample frame taken from a 64-frame-per-second photograph of a ballistic pendulum. The deflection of the block is measured

in degrees, the numbers being read from the pictures, and the height of rise calculated from the deflection and the length of the pendulum.

Other possibilities in dynamics suited to photography suggest themselves, such as falling bodies and billiard-ball collisions.

Some readers may believe that this method of laboratory study denies to the student the freedom of manipulating the apparatus. However, this disadvantage is minimized by having the student perform all operations except the actual photography (and, in the case of the ballistic pendulum, the actual firing). The disadvantage is further balanced by the improvement in accuracy which is gained when mechanical restrictions on the movement of the apparatus are removed.

¹Lemon and Ferenc, *Analytical experimental physics* (University of Chicago Press, 1946).

Letters to the Editor

The Demonstration of Nuclear Magnetic Resonance

IT does not seem to have been generally recognized that the demonstration of nuclear magnetic resonance requires only quite simple apparatus and should be within the scope of the average college physics department. In spite of the recent development of the subject there is a widespread recognition of its importance as a research technique but as yet there seems to be little realization that explanation of the basic principles coupled with an actual demonstration could form a useful addition to many undergraduate physics courses.

The possible importance of the subject from a didactic point of view has been emphasized by Dr. K. K. Darrow in an address in which he reviewed the experimental work done to date and there is no doubt of the interest aroused when the phenomena are displayed and explained. In the case of proton resonance no elaborate equipment is needed to make possible such a display.

Of the apparatus required the magnet itself is the major component. It should have a field strength of not less than 4000 oersteds and a gap width of 2 cm or more with pole pieces large enough to ensure homogeneity over a volume of the order of 1 cm³. If such a magnet is available the remainder of the equipment may be assembled without difficulty. A 300-volt power supply and an oscilloscope are required and a small regenerative detector and amplifier circuit will need to be built. Constructional details for this are identical with those given elsewhere¹ for a magnetic field strength meter based on the same principle. They need not be repeated here. Some simplification is possible, however, for the present purpose since neither portability nor a broad range of application is required. The probe and amplifier described in the paper referred to may thus be incorporated

into a single chassis and the so-called "wobbling" coils may be wound on the magnet pole pieces in any arrangement which will give a suitable wobbling amplitude. Also, the only sample coil required will be the one appropriate for the available magnetic field strength.

In summary: it has been pointed out that with the construction of a small electronic circuit and the use of standard laboratory equipment it is possible to display proton magnetic resonance.

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¹Hopkins, *Rev. Sci. Inst.* 20, 401 (1949).

Velocity of a Longitudinal Wave by an Elementary Method

ASSUME that a prismatic bar, of cross-sectional area A , density ρ and Young's modulus E , is subjected to a sudden compressive force uniformly distributed over the face BC (Fig. 1), causing a displacement $BB' = s$, and sup-

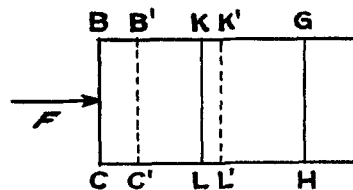


FIG. 1. Longitudinal wave traveling along a solid bar.

pose that the disturbance is transmitted in an infinitesimal time t to a section GH , at a distance $BG = x$ with a velocity v , so that $x = vt$. If we call a the average acceleration of BC during the time t , $s = at^2/2$, whence $a = 2s/t^2$.